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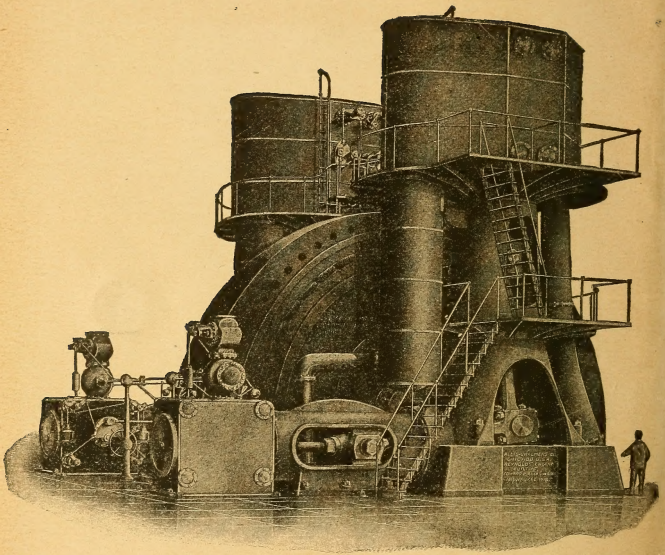

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By C. F. SWINGLE, M.E.

ELECTRICAL DIVISION

Containing only such information as Steam Engineers should know to successfully and economically run or manage an electrical plant

BY

HENRY C. HORSTMANN & VICTOR H. TOUSLEY

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INTRODUCTION

ENGINEERING DIVISION

In the following pages the author proposes to deal mainly with the *operation* of steam engines, boilers, feed pumps, and all the necessary adjuncts of a steam plant, rather than with the *construction* and *erection* of the same, although the designing and construction of steam machinery will receive some attention.

In order to successfully operate a steam plant the engineer in charge should, in addition to his other accomplishments, have at least sufficient technical knowledge to enable him to ascertain, by measurements and calculations, such very important points as the safe working pressure of his boiler, the most economical point of cut off for his engine, whether engine and boiler are properly proportioned for the work to be performed, and many other details which will be treated upon in their proper place.

Without a doubt the most successful operating engineers are those who combine practice with theory, and in order to obtain a practical working knowledge of steam engineering it is absolutely necessary that the young man who desires to become a successful engineer should start in the boiler-room, that he should thoroughly familiarize himself with all of the details of boiler management, and while his hands and eyes are thus gradually being trained to the practical part of the work he should at the same time be training his mind in the theoretical part by reading and studying technical books and journals relative to steam engineering. In order to facilitate this work a

series of practical questions will follow the close of each chapter, the answers to which may be found in the matter contained in the chapter. And now with the hope that a study of the following pages may prove to be a help to all into whose hands this book may come, the author respectfully dedicates it to his fellow craftsmen, the engineers of America.

C. F. S.

Engineering

CHAPTER I

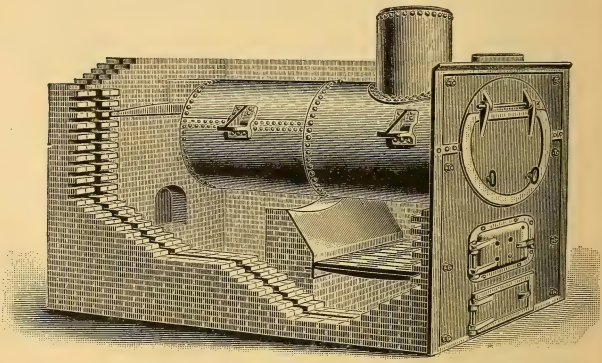
THE BOILER

Description of various types—Construction—Rules for ascertaining strength of sheet before and after punching—Strength of rivets—Single and double riveted seams—Triple riveted butt joints, strength of—Force tending to rupture a boiler—Rules for finding the safe working pressure of boilers—Bracing—Rules for bracing—Bracing domes.

It is hardly within the scope of this book to describe the many and varied types of metallic vessels known as steam boilers in use to-day for the generation of steam for power and other purposes. The author will deal mainly with those types most commonly used in this country for stationary service.

Description. These may be divided into four different classes. The first and most simple type, and the one from which the others have gradually evolved, is the plain cylinder boiler in which the heated gases merely pass under the boiler, coming in contact only with the lower half of the shell and then pass to the stack. These boilers are generally of small diameter (about 30 in.) and great length (30 ft.). Next comes the flue cylindrical boiler, which is somewhat larger in diameter than the former, generally 40 in. diameter and 20 to 30 ft. long, with two large flues 12 to 14 in. diameter extending through it. The return tubular boiler, consisting of a shell with tubes of small diam-

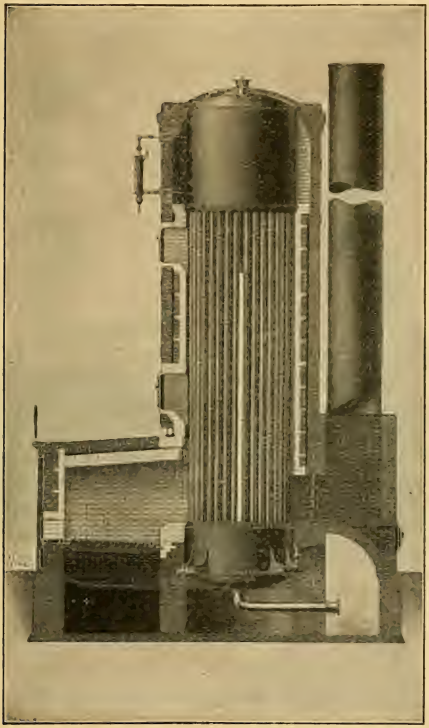
eter (2 to 4 in.) extending from head to head through which the hot gases from the furnace pass on their way to the stack. This boiler, which comes in the third class, is probably more extensively used in the United States for stationary service than any other type. The fourth class comprises the water tube boilers, in which the water is carried in tubes 3 to 4 in. in diameter, sometimes vertical and sometimes inclined, and connected at the top to one end of a steam drum,



STANDARD HORIZONTAL BOILER WITH FULL-ARCH FRONT SETTING.

and having the lower ends of the tubes connected to a mud drum, which is also connected to the opposite end of the steam drum, thus providing for a free circulation of the water. Of the latter type there have been many different kinds evolved during the last one hundred years, the majority of them having had but a brief existence, being compelled to obey the inexorable law of the survival of the fittest, and to-day there are a few excellent types of water tube boilers

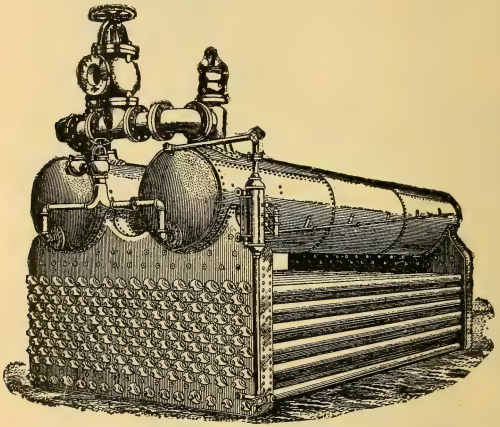
which have become standard and are being extensively used. The margin of safety as regards disastrous



WICKES VERTICAL WATER TUBE BOILER.

explosions appears to be in favor of the water tube boiler. It is not contended that they are entirely

exempt from the danger of explosion. On the contrary, the percentage of explosions of water tube boilers in proportion to the number in use is probably as large, if not larger, than it is with boilers of the shell or return tubular type, but the results are seldom so destructive of life or property, for the reason that if one or more of the tubes give way the pressure is released and the danger is past.



500 HORSE POWER HEINE WATER TUBE BOILER.

Construction. As the four classes of boilers above referred to are constructed of similar material, although assembled in different ways, the standard rules for calculating strength of joints, bracing, etc., may be applied to all.

The shell should be made of homogeneous steel of about 60,000 lbs. tensile strength. The thickness depending upon the pressure to be carried. The term

tensile strength means that it would take a pull of 60,000 lbs. in the direction of its length to break a bar of the material one inch square, or two inches wide by one-half inch thick, or three-eighths of an inch thick by 2.67 in. wide.

The heads are generally made one-eighth of an inch thicker than the shell.

Riveting. Boiler rivets should be of good charcoal iron, or a soft, mild steel of 38,000 lbs. to 40,000 lbs. T. S. No boiler is stronger than its weakest part, and it is evident that a riveted joint has not the full strength of the solid plate. In order to ascertain the safe working pressure of a boiler it is necessary to first determine the strength of the riveted seams, and the method of doing this is as follows: Assume the boiler to be of the horizontal tubular type, 60 in. in diameter by 16 ft. in length. The plates to be of steel ⅜ in. thick, having a tensile strength of 60,000 lbs. per square inch, the longitudinal seams to be double riveted and the girth seams to be single riveted. The pitch of the rivets, that is the distance from the center of one rivet hole to the center of the next one in the same row, to be for the double riveted seams 3¼ in. and for the single riveted seams 2⅜ in. The diameter of the rivets to be ⅞ in. and diameter of holes to be $1\frac{5}{16}$ in. Assume the rivets to have a T. S. of 38,000 lbs. per square inch of sectional area. First, find strength of a section of solid plate 3¼ in. wide, which is the width between centers of rivet holes before punching.

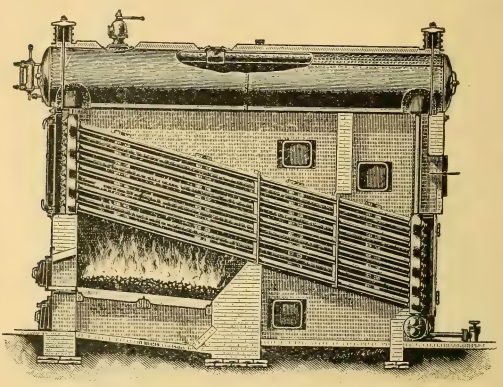
Rule 1. Pitch × thickness × T. S. Thus, 3.25 × .375 × 60,000 = 73,125 lbs., strength of solid plate.

Second, find strength of net section of plate, meaning that portion of plate left after deducting the diam-

eter of one hole $\frac{15}{16}$ in., which expressed in decimals = .9375 in. from the width of plate before punching.

Rule 2. Pitch – diameter of hole × thickness × T. S. Thus, 3.25 – .9375 × .375 × 60,000 = 52,031 lbs., strength of net section of plate.

Third, find strength of rivets. In calculating the strength of rivets in a double riveted seam, the sectional area of two rivets must be considered, taking

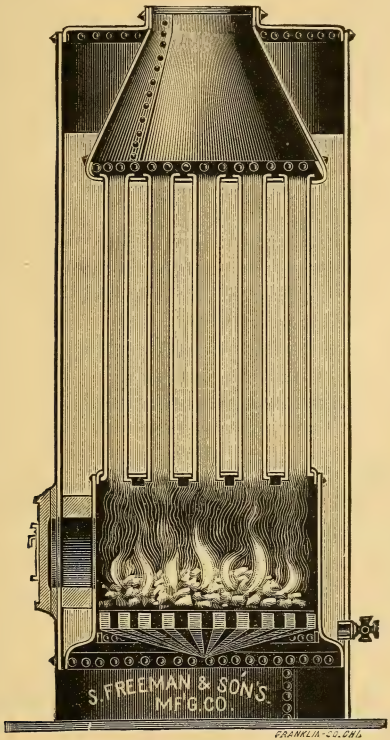


BABCOCK AND WILCOX BOILER.

one-half the area of two rivets in the first row, and the area of another rivet in the second row. The area of a $\frac{7}{8}$-in. rivet is .6013 in.. but when in position it is assumed to fill the hole $\frac{15}{16}$ in. Consequently, its area would then be .69 in. and its strength is found by Rule 3.

Rule 3. Sectional area × T. S. Thus, .69 × 38,000 = 26,220 lbs., strength of one rivet, and multiplying by 2, as there are two rivets, the result is 26,220 × 2 = 52,440

lbs., strength of rivets in the seam under consideration. It thus appears that the plate is the weakest por-



VERTICAL FIRE BOX BOILER.

tion and the percentage of strength retained is found by multiplying 52,031 by 100 and dividing by 73,125,

the strength of solid plate. Thus, $\frac{52{,}031 \times 100}{73{,}125} = 71.1$ per cent.

The query might arise, why is the diameter of one rivet hole deducted from the pitch when figuring the strength of net plate? The answer is, that in punching the holes one-half the diameter of each hole is cut from the section designated, thereby reducing its width by just that amount.

The 71.1 per cent. obtained by the calculation represents the strength of the boiler as compared to the strength of the sheet before punching, and should enter into all calculations for the safe working pressure.

It is usual in practice to figure the strength of a double-riveted seam at 70 per cent. of the strength of the solid plate. The strength of triple-riveted butt joints may be calculated by taking a section of plate along the first row of rivets and estimate it as a single-riveted joint, then add to this result the strength of rivets in the second and third rows for a section of the same width. In properly designed triple-riveted butt joints the percentage of strength retained is 88, and some recent achievements in designing have shown the remarkable result of quadruple-riveted butt joints retaining as high as 92 to 94 per cent. of the strength of the solid plate.

Bursting Pressure. The query might arise, why should the longitudinal or side seams require to be stronger than the girth or round about seams? The answer is, that the force tending to rupture the boiler along the line of the longitudinal seams is proportional to the diameter divided by two, while the stress tending to pull it apart endwise is only one-half that, or proportional to the diameter divided by four.

To illustrate, let Fig. 1 represent the shell of the boiler heretofore referred to, ignoring for the time being the tubes and braces, and consider the boiler simply as a hollow cylinder. Now the total force tending to rupture the boiler along the line of the girth seams or in the direction of the horizontal arrows = area of one head in square inches × pressure in pounds per square inch. It is true that the pressure is exerted against both heads, but the area of one head can only be considered for the reason that the two stresses are exerted against each other just as in the case of two horses pulling against each other, or in opposite direction on the same chain. The stress on the chain will

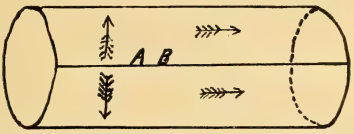


FIGURE 1.

be what each horse (not both) pulls. To further illustrate, suppose one of the horses to be replaced by a permanent post or wall and let one end of the chain be attached thereto. One head or one side of the boiler pulls against the other, and the stress on the seams is the force with which each (not both) pulls. Referring again to Fig. 1, area of one head = $60^2 \times .7854 = 2827.4$ sq. in. Suppose there is a pressure of 10 lbs. per square inch in the boiler. Then total stress on the girth seams = $2827.4 \times 10 = 28,274$ lbs. Opposed to this pull is the entire circumference of the boiler, which is $60 \times 3.1416 = 188.5$ in. Therefore, dividing total pressure (28,274 lbs.) by the circumference in inches (188.5) will give 150 lbs. as the stress on each inch of the

girth seams. While the stress on each inch of the longitudinal seams or along the line A B, Fig. 1, and which is exerted in the direction of the vertical arrows, is pressure (10 lbs.) × one-half the diameter (30 in.) = 300 lbs. One-half the diameter is used because the pressure in any direction is effective only on the surface at right angles to that direction.

The formula for finding the bursting pressure of a boiler may be expressed as follows:

$B = \frac{T.S. \times T}{R}$ in which B = bursting pressure.
T.S. = tensile strength.
T = thickness of sheet.
R = radius or one-half the diam.

Example. T. S. = 55,000 lbs. per square inch.
T = ⅜ in. (expressed decimally = .375 in.).
R = 30 in.

Then 55,000 × .375 ÷ 30 = 687.5 lbs. per square inch, which is the pressure at which rupture would take place provided there were no seams in the boiler and the original strength of the sheet was retained, but, as has been seen, a certain percentage of strength is lost through punching or drilling the necessary rivet holes, and this must be taken into account.

The formula now becomes, for double riveting, $B = \frac{T.S. \times T \times .70}{R}$, in which the letters preserve the same value as in the original formula, but the result is reduced by multiplying by the decimal .70, which represents the percentage of strength retained by double-riveted seams. Consequently B will now =

$$\frac{55{,}000 \times .375 \times .70}{30} = 481 \text{ lbs.}$$

In case the seams are all single riveted .56 must be

substituted for .70, and with triple-riveted butt joints .88 can safely be used.

Safe Working Pressure. In order to ascertain the safe working pressure of a boiler it is necessary first to calculate the bursting pressure and divide this by another factor called the factor of safety. The one most commonly used for boilers is 5, or in other words the safe working pressure = one-fifth the bursting pressure. In the case of the boiler under consideration, the safe pressure would be $481 \div 5 = 96$ lbs., at which point the safety valve should blow off.

Bracing. Every engineer can easily ascertain for himself whether the boilers under his charge are properly braced or not. The parts that require bracing are: all flat surfaces, such as the sides and top of the fire-box in boilers of the locomotive type, and those portions of the heads above and below the tubes in horizontal tubular boilers, also the top of the dome.

The stress per square inch of sectional area on braces and stays should not exceed 6,000 lbs. It is customary to consider the flange of the head and the top row of tubes as sufficient bracing for a space two inches wide above the tubes and the same distance around the flange. Therefore the part of the head to be braced will be the segment contained within a line drawn two inches above the top row of tubes and two inches inside the flange.

In order to ascertain the number of braces required for a given boiler head, three factors are necessary: first, the area of the segment in square inches; second, the diameter and T. S. of the braces, and third, the pressure to be carried. By the use of Table No. 1 the areas of segments of boiler heads ranging from 42 to 72 in. in diameter can easily be obtained. Assume the

boiler to be 60 in. in diameter, distance from top of tubes to top of shell 24 in. Deduct 4 in. for surface braced by top row of tubes and flange, leaving the height of segment to be braced 20 in.

TABLE I

Diameter of Boiler.	Ditsance from Tubes to Shell.	Height of Segment.	Constant.
42 in.	15 in.	11 in.	.16314
44 in.	17 in.	13 in.	.1936
48 in.	19 in.	15 in.	.20923
54 in.	21 in.	17 in.	.21201
60 in.	24 in.	20 in.	.22886
66 in.	25 in.	21 in.	.214
72 in.	29 in.	25 in.	.24212

Rule. Multiply the square of the diameter of the boiler by the constant number found in right hand column opposite column headed diameter.

Example. $60 \times 60 \times .22886 = 823.89$ sq. in., area of segment to be braced. Find number of braces required. Assume the braces to be 1⅛ in. in diameter and of a T. S. of 38,000 lbs. per square inch of section. The area of one brace will be .994 sq. in., which × 6,000 lbs. gives 5,964 lbs. as the stress allowable on each brace. Suppose the pressure to be carried is 100 lbs. per square inch. There will be area of segment (823.89 sq. in.) × pressure (100 lbs.) = 82,389 lbs., total stress. Dividing this result by 5,964 lbs. (the capacity of each brace) gives 13.8 braces as the number needed. In practice there should be fourteen.

Having a T. S. of 38,000 lbs. and using 6 as the factor of safety, each brace could safely sustain a pull of 6,295 lbs. Therefore it is evident that the above mentioned load for each brace is well within the limit. For convenience in calculating the areas of segments

of circles, other than those mentioned in Table 1, the following rule is given:

Referring to Figure 2 it is desired to find the area of the segment contained within the lines A B C E. It will be necessary first to find the area of the sector bounded by the lines A B C D. This is done by multiplying one-half the length of the arc, A B C, by the radius, D B. Having obtained the area of the sector, the next step is to find the area of the triangle bounded by the lines A E C D and subtract it from the area of the sector. The remainder will be the area of the segment. Having found the area of the surface to be braced, and the number of braces required, it now becomes necessary to consider the spacing of the same.

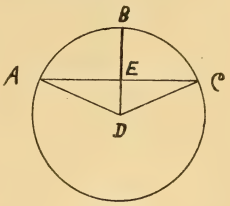


FIGURE 2.

Rule. Divide area to be braced by the number of braces, and extract the square root of quotient.

Example. 823.89 ÷ 14 = 58.8 sq. in. to be allotted to each brace. Extract square root of 58.8 and the result is 7.68 inches, which is the length of one side of the square which each brace will be required to sustain.

For internally fired boilers the same rules can be applied except that the surfaces to be braced are generally of rectangular shape and consequently the area is more easily figured than in the case of segments. That part of the head below the tubes also requires to be braced, and two braces are generally sufficient, as at A and B, Fig. 3. In the case of domes it is safe to consider the portion of the head within

three inches of the flange as sufficiently braced. Then suppose the dome to be 36 in. in diameter, there will remain a circle 30 in. in diameter to be braced. The circumference of this circle is 94.2 in. and the pitch, or distance from center to center of the braces, being 7.6 in., the number of braces required is found by dividing 94.2 by 7.6, giving 12 braces. These braces should be located along a line which is one-half the pitch, or 3.8 in., within the circumference of the 30-in. circle. The space immediately surrounding the hole cut for the steam outlet will be sufficiently reënforced by the flange riveted on for the reception of the steam pipe. All holes cut in boilers, such as man holes, hand holes, and those for pipe connections, above two inches should be properly reënforced by riveting either inside or outside a wrought-iron or steel ring or flange of such thickness and width as to contain at least as much material as has been cut from the hole.

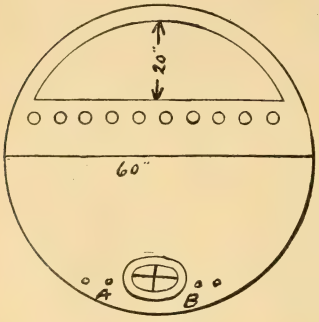


FIGURE 3.

Questions

1. How many types of steam boilers are there?
2. What kind of boilers are included in type one?
3. Describe a boiler belonging to type two.
4. Describe a boiler of the third type.

5. How is a boiler of the fourth type constructed?

6. In what respect do water tube boilers have the advantage over other types as regards explosions?

7. What kind of material should be used in the construction of boilers?

8. What does the term tensile strength (T. S.) mean?

9. What is the usual T. S. of steel boiler plates?

10. How much thicker than the shell plates should the heads be?

11. Of what material and of what T. S. should the rivets be?

12. Is a riveted joint as strong as the solid plate?

13. What is meant by the pitch of the rivets?

14. What is the usual pitch for a double riveted seam?

15. Give the rule for finding the strength of the solid plate before punching.

16. What is meant by net section of plate?

17. What is the rule for finding strength of net section of plate?

18. How is the strength of rivets in a double riveted seam calculated?

19. What percentage of the strength of solid plate is usually retained in a double riveted seam?

20. How is the strength of a triple riveted butt strap joint calculated?

21. What per cent. of the original strength of the sheet is retained in a properly designed triple riveted butt strap joint?

22. Why should the side seams be stronger than the girth seams?

23. What is the rule for finding the bursting pressure of a boiler?

24. How is the safe working pressure of a boiler calculated?

25. What parts of a boiler require bracing internally?

26. What stress per square inch of sectional area may be allowed on braces?

27. How is the number of braces required for any part of the boiler obtained?

28. How should domes be braced?

CHAPTER II

BOILER SETTINGS AND APPURTENANCES

Foundations—Brick work, etc.—Grate surface—Insulation—Water columns—Steam gages—Safety valves—Rules for finding areas of—Fusible plugs and where to place them—Domes and mud drums—Feed pipes—A good arch for the back connection—Blow off pipes and cocks—Surface blow off and circulating system—Feed pumps and feed water heaters—Injectors—Saving effected by heating the feed water with exhaust steam—Apparatus for making coal tests—Heating surface—Rules for figuring the same.

Settings. In the case of internally fired boilers the matter of setting resolves itself into the simple point of securing a sufficiently solid foundation, either of stone or brick laid in cement, for the boiler to rest upon.

But with horizontal tubular or water tube boilers the matter of brick work becomes important, and particular attention should be paid to securing a good foundation for the walls and great care exercised in building them in such manner that the expansion of the inner wall or lining will not seriously affect the outer walls. This can be done be leaving an air space of two inches in the rear and side walls, beginning at or near the level of the grate-bars and extending as high as the fire line, or about the center line of the boiler. Above this height the wall should be solid. Fig. 4 shows a plan and an end elevation illustrating this idea. The ends of some of the bricks should be allowed to project at intervals from the outer walls across the air space, so as to come in touch with the inner walls.

Where boilers are set in batteries of two or more the middle or party walls should be built up solid from the foundation. All parts of the walls with which the

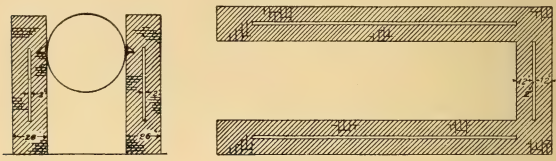


FIGURE 4.

fire comes in contact should be lined with fire brick, every fifth course being a header to tie the lining to the main wall.

Bridge walls should be built straight across from wall to wall of the setting, and should not be curved to conform to the circle of the boiler shell. The proper

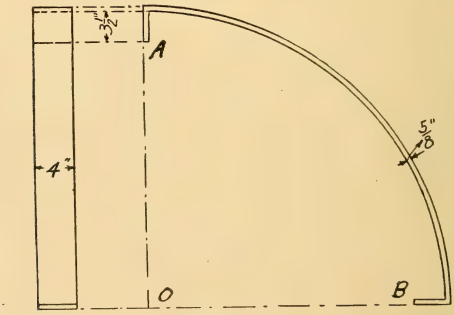


FIGURE 5.

distance from the top of the bridge wall to the bottom of the boiler varies from eight to ten inches, depending upon the size of the boiler. The space back of the

bridge wall, called the combustion chamber, can be filled in with earth or sand, and should slope gradually downward from the back of the bridge wall to the floor level at the rear wall, and should be paved with hard burned brick. The ashes and soot can then be easily cleaned out by means of a long-handled hoe or scraper inserted through the cleaning out door, which should always be placed in the back wall of every boiler setting.

Back Arches. A good and durable arch can be made

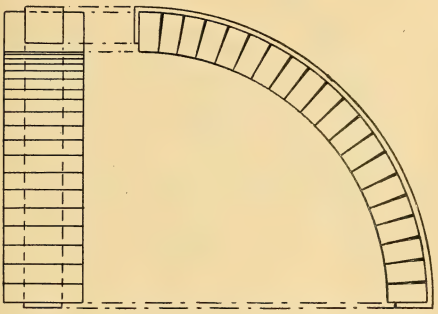


FIGURE 6.

for the back connection, extending from the back wall to the boiler head, by taking flat bars of iron $\frac{5}{8} \times 4$ in., cutting them to the proper length and bending them in the shape of an arch, turning four inches of each end back at right angles, as shown in Fig. 5. The distance O-B should equal that from the rear wall to the boiler head, and the height, O-A, should be about equal to O-B, and should bring the point A about two inches above the top row of tubes. The clamp thus formed is filled with a course of side arch fire brick,

Fig. 6, and will form a complete and self-sustaining arch, the bottom, B, resting on the back wall, and the top, A, supported by an angle iron riveted across the boiler head about three inches above the top row of tubes. See Figs. 7 and 8.

Enough of these arches should be made so that when laid side by side they will cover the distance from one side wall to the other across the rear end of the boiler. A fifty-four-inch boiler would thus require six clamps,

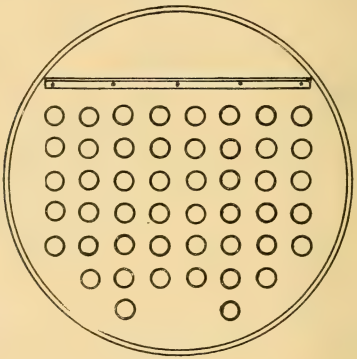


FIGURE 7.

a sixty-inch boiler seven clamps, and a seventy-two-inch boiler would require eight clamps; the length of a fire brick being about nine inches. In case of needed repairs to the back end of the boiler the sections can be lifted off, thus giving free access to all parts, and when the repairs are completed the arches can be reset with very little trouble and much less expense than the building of a solid arch would necessitate. This form of segmental arch allows ample freedom for expansion

of the boiler, in the direction of its length, without leaving an opening when the boiler contracts.

The crosswise construction of arch bars, while affording equal facility in repair work, is necessarily more expensive than the form here described, and is also open to the objection that it cannot follow the contracting boiler and maintain a tight joint or connection

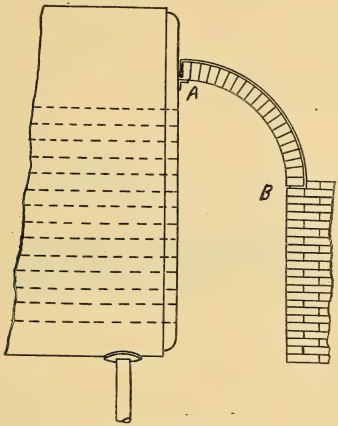


FIGURE 8.

between the back arch and the rear head above the tubes.

Boiler walls should always be well secured in both directions by tie rods extending throughout the entire length and breadth of the setting, whether there be one boiler or a battery of several. The bottom rods should be laid in place at the floor level when starting the brick work, and the top rods extending transversely across the boilers can be laid on top of the boilers.

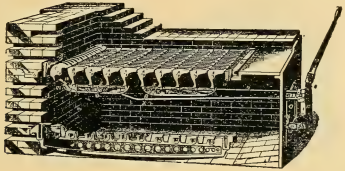
The top rods extending from front to back can be laid in the side walls or rest on top of them. All tie rods should be at least one inch in diameter, and for batteries of several boilers they should be larger. The rods should extend three or four inches beyond the brick work, with good threads and nuts on each end to receive the buck stays. In laying down the transverse tie rods they should be located so as to allow the buck stays to bind the brick work where the greatest concentration of heat occurs.

Horizontal boilers should always be set at least one inch lower at the back end than at the front, to make sure that the rear ends of the tubes will be covered with water so long as any appears in the gauge glass, provided of course that the lower end of the glass is properly located with reference to the top row of tubes, which will be discussed later on. Upon the brick work and immediately under each lug of the boiler there should be laid in mortar a wrought or cast iron plate several inches larger in dimension than the bearing surface of the lug and not less than one inch in thickness. Upon each of these plates there should be placed two rollers made of round iron 1 or 1⅛ in. in diameter, and as long as the width of the lug. These rollers should be placed at right angles to the length of the boiler, in such a position that the lug will bear equally upon them. The object of the rollers is to prevent disturbance of the brick work by the endwise expansion and contraction of the boiler.

Grate Surface. The number of square feet of grate surface required depends upon the size of the boiler. A good rule and one easy to remember is to make the length of the grates equal to the diameter of the boiler. The width, of course, will depend upon the construc-

tion of the furnace. If the fire brick lining is built perpendicular, the width of grate will be about equal to the diameter of the boiler. On the other hand, if the lining is given a batter of three inches, starting at the level of the grate, then the width will be reduced six inches. It is customary to allow one square foot of grate surface to every 36 sq. ft. of heating surface. The distance of the grate-bars from the shell of the boiler varies from 24 to 28 in., according to the dimensions of the boiler.

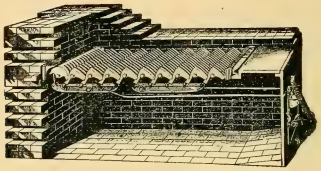
Insulation. All boilers should be well protected from the cooling influence of outside air, if economy



M'CLAVE'S GRATES.

of fuel is any object. The tops of horizontal boilers should be covered with some kind of heat insulating material, or arched over with common brick, leaving a space of two inches between the boiler and the arch. The resulting saving in fuel will far more than compensate for the extra expense in a very short time. All cracks in the side and rear walls should be carefully pointed up with mortar or fire clay. One source of heat loss in return flue boilers is short circuiting from the furnace to the breeching, caused by the arches over the fire doors becoming loose and shaky, and allowing considerable of the heat to escape directly to the stack instead of passing under the boiler and

through the tubes. Another bad air leak often occurs at the back connection when the arch rests wholly upon iron bars imbedded in the side walls. This leak, as has already been noted, is caused by the expansion of the boiler, which gradually pushes the arch away from the back head until, in the course of time, there will be a space of $\frac{5}{8}$ in. and sometimes $\frac{3}{4}$ in. between the head and the arch. The obvious remedy for this is an arch that will go and come with the movement of the boiler, and such an arch can be secured by building it in sections, as illustrated by Fig. 3, and then riveting a piece of angle iron to the boiler head, above

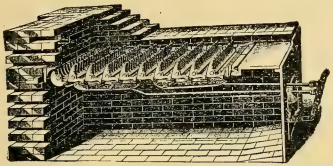


M'CLAVE'S GRATES.

the top row of tubes for the upper ends of the sections to rest upon, as already described. It will be seen that within all possible range of boiler movement in either direction the arch will, with this construction, always remain close to the head.

Water Columns. Water columns should be so located as to bring the lower end of the gauge glass exactly on a level with the top of the upper row of tubes, thus always affording a perfect guide as to the depth of water over the tubes. Many gauge glasses are placed too low, and water tenders and firemen are often deceived by them unless their positions with relation to the tubes are carefully noted.

The only safe plan for an engineer to pursue in taking charge of a steam plant is to seize the first opportunity for noting this relation. When he has washed out his boilers he may leave the top man-hole plates out while refilling them, and when the water stands at about four inches over the top row of tubes, the depth of water in the glass should be measured. He should do this with every boiler in the plant, and make a memorandum for each boiler. He will then know his bearings with regard to the safe height of water to be carried in the several gauge glasses. If he finds any of them are too low, he should lose no time

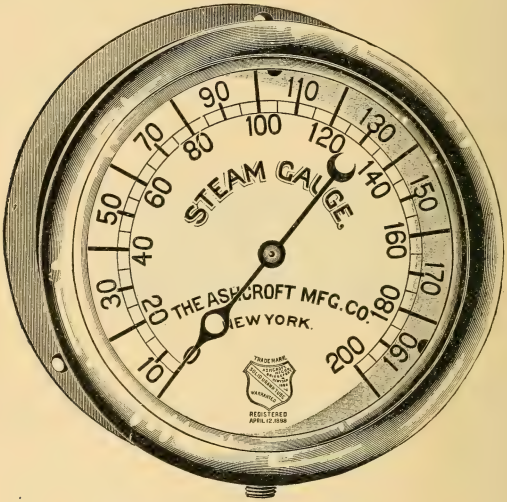


M'CLAVE'S GRATES.

in having them altered to comform to the requirements of safety. The position of the lower gauge cock should be three inches above the top row of tubes.

In making connections for the water column plugged crosses should always be used in place of ells. Brass plugs are to be preferred if they can be obtained; but whether of brass or iron, they should always be well coated with a paste made of graphite and cylinder oil before they are screwed in. They can then be easily removed when washing out the boiler, so as to allow the scale, which is sure to form in the lower connection, to be cleaned out. The best point at which to connect the lower pipe with the boiler is in the lower part of the

head just below the bottom row of tubes, and near the side of the boiler on which the water column is to stand; 1¼ or 1½ in. pipe should be used in all cases. The top connection can be made either in the head near the top, or in the shell. A ¾ or 1 in. drain pipe should be led into the ash pit, fitted with a good reli-

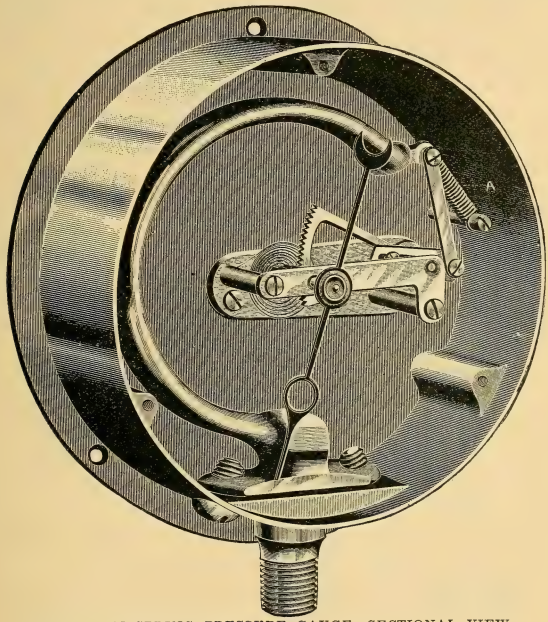


AUXILIARY SPRING PRESSURE GAUGE.

able valve which should be opened at frequent intervals to allow the mud and dirt to blow out of the water column and its connections. This is a very important point, and great care should be taken to keep the water column and all its connections thoroughly clean at all times.

One of the best indications that some portion of the

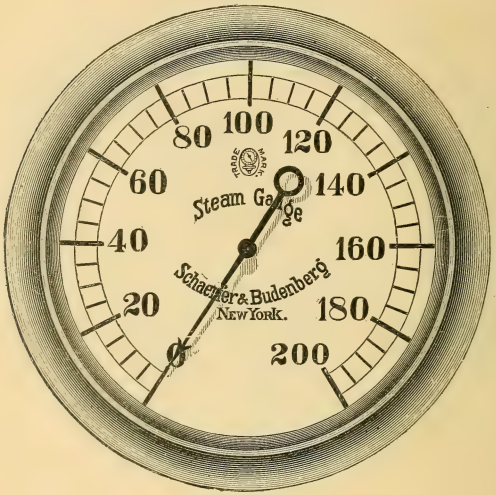
connections between the water glass and the boiler is choked or plugged with scale, is when there is no perceptible movement of the water in the glass. When the connections are free and the boiler is being fired,



AUXILIARY SPRING PRESSURE GAUGE, SECTIONAL VIEW.

there is always a slight movement of the water up and down in the glass, and when there is no perceptible movement it is time to look for the cause at once. Many instances of burned tubes have occurred, and

even explosions caused by low water in boilers while the gauge glass showed the water to be at a safe height. But owing to the connections having become plugged with scale, the water in the glass had no connection whatever with that in the boiler, and the water column was therefore worse than useless.



Steam Gauges. As water columns are made at present the steam gauge is usually connected at the top of the column. This makes a handsome and convenient connection, although theoretically the proper method would be to connect the steam gauge directly with the dome or the steam space of the shell. There should always be a trap or siphon in the gauge pipe in order

to retain the water of condensation, so as to prevent the hot steam from coming in contact with the spring.

If at any time the water is drained from the siphon, care should be exercised in turning on the steam again by allowing it to flow in very slowly at first until the siphon is again filled with water.

The steam gauge and the safety valve should be compared frequently by raising the steam pressure high enough to cause the valve to open at the point for which it is set to blow.

Safety Valves. The modern pop valve is generally reliable, but, like everything else, if it is allowed to stand idle too long it is likely to become rusty and stick. Therefore it should be allowed to blow off at least once or twice a week in order to keep it in good condition.

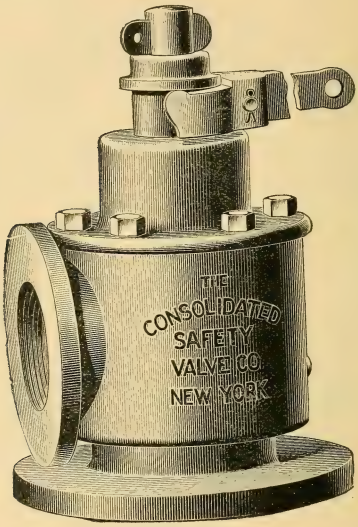
Most pop valves for stationary boilers are provided with a short lever, and if at any time the valve does not pop when the steam gauge shows the pressure to be high enough, it can generally be started by a light blow on the lever with a hammer.

The ratio of safety valve area to that of grate surface is, for the old style lever and weight valve, 1 sq. in. of valve area for each 2 sq. ft. of grate surface, and for pop valves 1 sq. in. of valve area for each 3 sq. ft. of grate surface.

Each boiler in a battery should have its own safety valve, and, in fact, be entirely independent of its mates as regards safety appliances.

One example of safety valve computation will be given. Suppose the grate surface of a boiler is $5 \times 6 = 30$ sq. ft, what should be the diameter of the lever safety valve? The required area of the valve is $30 \div 2 = 15$ sq. in. Then $15 \div .7854 = 19$, which is the

square of the diameter of the valve. Extracting the square root of 19 gives 4.35 in. diameter of valve. In actual practice one 5 in. or two 3 in. lever safety valves would be required. If a pop valve is to be used the required area is 30 ÷ 3 = 10 sq. in. Then 10 ÷ .7854 = 12.73 = square of diameter of valve. Extract the

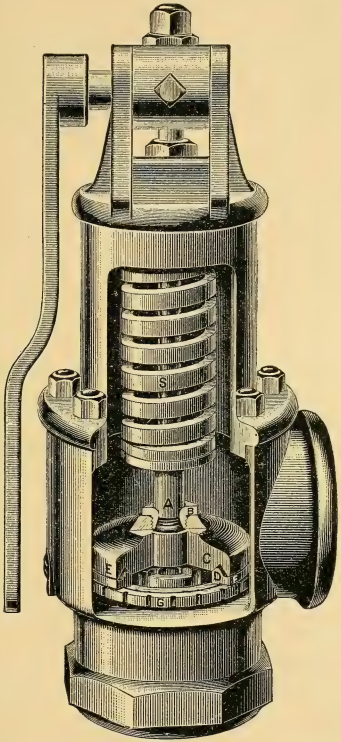


POP VALVE.

square root of 12.73 and the result is 3.6 in. = diameter of valve. In practice a 4 in. valve would be required.

Fusible Plugs. A fusible plug should be inserted in that part of the heating surface of a boiler which is first liable to be overheated from lack of water.

In a horizontal tubular or return flue boiler the proper location for the fusible plug is in the back head



INSIDE VIEW OF A POP SAFETY VALVE.

about 1½ or 2 in. above the top row of tubes. In fire-box boilers the plug can be put into the crown sheet

directly over the fire. These plugs should be made of brass with hexagon heads and standard pipe threads, in sizes ½, ¾, 1 in., or even larger if desired. A hole drilled axially through the center and counter sunk in the end that enters the boiler is filled with an alloy of such composition that it will melt and run out at the temperature of the dry steam at the pressure carried in the boiler. Thus, if the water should get below the plug the dry steam, coming in contact with the fusible alloy, melts it and, escaping through the hole in the plug, gives the alarm, and in case of fire-box or internally fired boilers the steam will generally extinguish the fire also. The hole is counter sunk on the inner end of the plug so as to retain the fusible metal against the boiler pressure. These plugs should be looked after each time the boilers are washed out, and all dirt and scale should be cleaned off in order that the fusible metal may be exposed to the heat.

Another type of fusible plug consists of a small brass cylinder into one end of which is screwed a plug filled with a metal which will fuse at the temperature of dry steam at the pressure which is to be carried in the boiler. The other end of the cylinder is reduced and fitted with a small stop valve and threaded to screw into a brass bushing inserted into the top of the boiler shell. This bushing also receives at its lower end a piece of ½ or ¾ in. pipe which extends downwards to within 2 in. of the top row of tubes, or the crown sheet if the boiler is internally fired. The principle of the device is that in case the water falls below the lower end of the pipe, steam will enter, fuse the metal in the plug, and be free to blow and give warning of danger. Some of these appliances are fitted with whistles which are sounded in case the steam gets access to

them. But even with such devices no engineer can afford to relax his own vigilance and depend entirely upon the safety appliances to prevent accidents from low water.

Domes and Mud-Drums. As a general proposition, both mud drums and domes are useless appendages to steam boilers. There are, no doubt, instances where they may serve a purpose, but as a rule their use is of no advantage to a boiler. Neither are the so-called circulating systems, sometimes attached to return tubular boilers, of any real value. These consist of one or more 4 to 6 in. pipes extending under the boiler from front to back through the furnace and the combustion chamber and connected to each end of the boiler.

Feed Pipes. Authorities differ in regard to the proper location of the inlet for the feed pipe, but upon one point all are agreed, namely, that the feed water, which is always at a lower temperature than the water in the boiler, should not be allowed to come directly in contact with the hot boiler sheets until its temperature has been raised to within a few degrees of the temperature of the water in the boiler. Certainly one of the most fruitful sources of leaks in the seams and around the rivets is the practice of introducing the feed water into the bottom either at the back or front ends of boilers, as is too often the case. The cool water coming directly in contact with the hot sheets causes alternate contraction and expansion, and results in leaks, and very often in small cracks in the sheet, the cracks extending radially from the rivet holes. It would appear that the proper method is to connect the feed pipe either into the front head just above the tubes, or into the top of the shell. The

nipple entering the boiler should have a long thread cut on the end which screws into the sheet, and to this end inside the boiler there should be connected another pipe which shall extend horizontally at least two-thirds of the length of the boiler, resting on top of the tubes, and then discharge. Or, what is still better, allow the internal pipe to extend from the entering nipple at the front end to within a few inches of the back head, then at right angles across the top of the tubes to the other side, and from there discharge downward. By this method the feed water is heated to nearly, if not quite, the temperature of the water in the boiler before it is discharged. One of the objections to this system is the liability of the pipe inside the boiler to become filled with scale and finally plugged entirely. In such cases the only remedy is to replace it with new pipe. But the great advantage of having the water thoroughly heated before being discharged into the boiler will much more than compensate for the extra expense of piping, and the general idea of introducing the feed water at the top instead of at the bottom of the boiler is therefore recommended as being the best.

The diameter of feed pipes ranges from 1 in. for small sized boilers, up to 1½ and 2 in. for boilers of 54 to 72 in. in diameter. It is not good policy to have the feed pipe larger than necessary for the capacity of the boiler; because it then acts as a sort of cooling reservoir for the feed water, and may cause considerable loss of heat.

For batteries of two or more boilers it is necessary to run a main feed header, with branch pipes leading to each boiler. The header should be large enough to supply all the boilers at the same time, should it ever

become necessary to do so. The header can be run along the front of the boilers just above the fire doors with the branch pipes running up on either side, clear of the flue doors and entering the front connection, or smoke arch, and the boiler head at a point two inches above the tubes. There should always be a valve in each branch pipe between the check valve and the header for the purpose of regulating the supply of water to each boiler, and also for shutting off the pump pressure in case of needed repairs to the check valve. Another valve should be placed between the check valve and the boiler. By this arrangement it is always possible to get at the check valve when it is out of order.

Blow off Pipes. Blow off pipes should always be connected with the lowest part of the water space of a boiler. If there is a mud-drum, then of course the blow off should be connected with it; but if there is no mud-drum, the blow off should connect with the bottom of the shell, near the back head, extend downwards to the floor of the combustion chamber, and thence horizontally out through the back wall, where the blow off cock can be located.

The best blow off cocks are the asbestos packed iron-body plug cocks, which are durable and safe. A globe valve should never be used in a blow off pipe, because the scale and dirt will lodge in it and prevent its being closed tightly. A straight way or gate valve is not so bad, but an asbestos packed plug cock is undoubtedly the best and safest.

In order to protect the blow off pipe from the intense heat, a shield consisting of a piece of larger pipe can be slipped over the vertical part before it is connected.

Blow off cocks should be opened for a few seconds once or twice a day, to allow the scale and mud to be blown out. If neglected too long they are liable to become filled with scale and burn out. A plan which is said to give good results is to connect a tee in the horizontal part of the pipe, and from this tee run a 1 in.

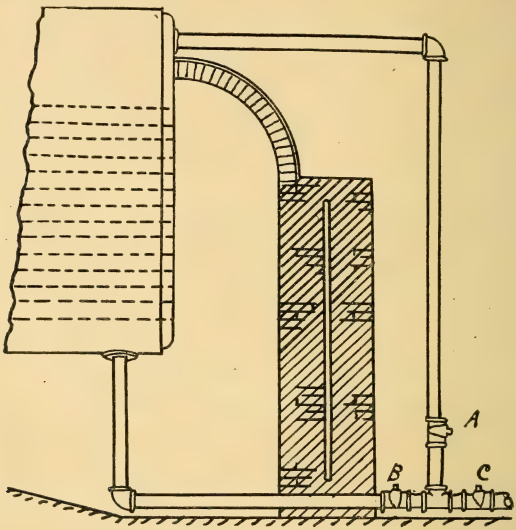


FIGURE 9.

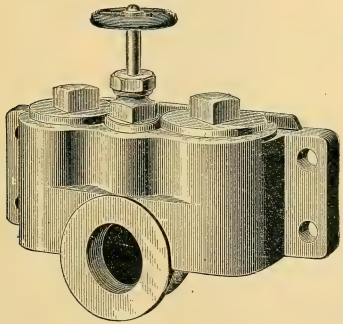
pipe to a point in the back head at the water level. It is claimed that this will cause a circulation of water in the pipe and prevent the formation of scale.

A surface blow off is a great advantage, especially if the water is muddy or liable to foam. By having the surface blow off connected on a level with the

water line a large amount of mud and other matter which is kept on the surface by the constant ebullition can be blown out.

A combination surface blow off, bottom blow off, and circulating system can be arranged by a connection such as illustrated in Fig. 9. By closing cock A and opening cocks B and C the bottom blow off is put in operation; by closing B and opening A and C the surface blow off is started, and by closing C and leaving A and B open the device will act as a circulating system. The pipe should be of the same size throughout. Blow off pipes should be of ample size, never less than 1¼ in., and from that to 2½ in., depending upon the size of the boiler.

Feed Pumps and Injectors. The belt driven power pump is the most economical boiler feeder, but is not

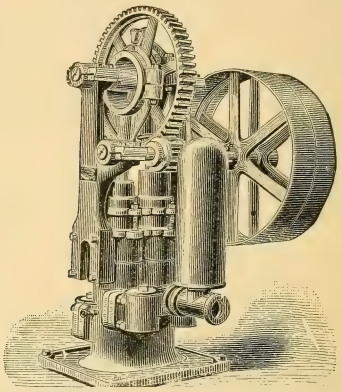


DIFFERENTIAL VALVE, DAVIS PUMP.

the most convenient nor the safest. When the engine stops, the pump stops also, and sometimes it happens that the belt gives way and the pump stops at just

the time when the boiler is being worked the hardest.

The modern double acting steam pump, of which there are many different makes to choose from, is without doubt the most reliable boiler feeding appliance and the one best adapted to all circumstances and conditions, although it is not economical in the

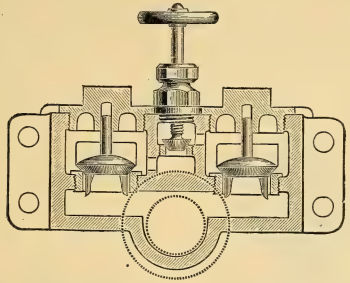


DAVIS BELT DRIVEN FEED PUMP.

use of steam, since the principle of expansion cannot be carried out with the pump as with the engine.

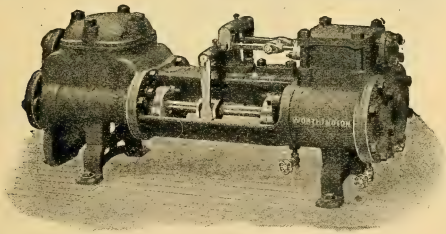
In selecting a feed pump care should be exercised to see that it is of the proper size and capacity to supply the maximum quantity of water that the boiler can evaporate. This may be ascertained by taking into consideration the amount of heating surface and the required consumption of coal per square foot of grate surface per hour. First, take the coal consumption. Assume the boiler to have 30 sq. ft. of grate surface,

and that it is desired to burn 15 lbs. of coal per square foot of grate per hour, which is a good average with the ordinary hand fired furnace using bituminous coal.



SECTIONAL VIEW OF DIFFERENTIAL VALVE.

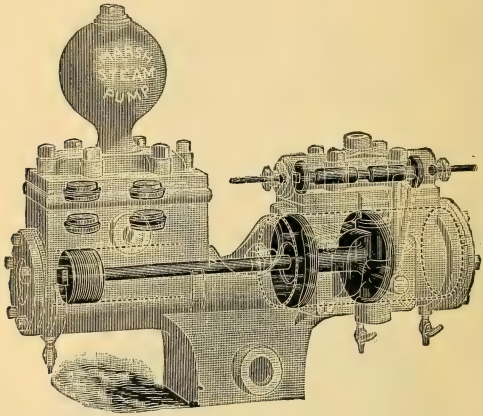
Suppose the boiler is capable of evaporating 8 lbs. of water per pound of coal consumed. Then $30 \times 15 \times 8 =$ 3,600 lbs. of water evaporated per hour. Dividing



WORTHINGTON DUPLEX BOILER FEED PUMP.

3,600 by 62.4 (the weight of a cubic foot of water in pounds) gives 57.6 cu. ft. per hour, which, divided by 60, gives 0.96 cu. ft. per minute. This multiplied by

1,728 (number of cubic inches in a cubic foot) gives 1,659 cu. in. per minute which the pump is required to supply. Suppose the pump is to make forty strokes per minute, and the length of stroke is five inches. Then 1659 ÷ 40 = 41.47 cu. in. per stroke, which, divided by 5 (length of stroke in inches) gives 8.294 sq. in. as the required area of water piston. 8.294 ÷ .7854 = 10.56, which is the square of the corresponding diam-



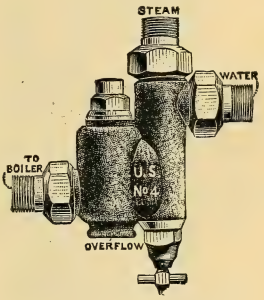
PHANTOM VIEW OF MARSH INDEPENDENT STEAM PUMP.

eter, and the square root of 10.56 = 3.25. So, theoretically, the size of the water end of the pump would be 3¼ in. in diameter by 5 in. stroke; but as it is always safer to have a reserve of pumping capacity, the proper size of the pump would be 3½ in. in diameter by 5 in. stroke, with a steam cylinder of 6 or 7 in. in diameter.

There is another rule for ascertaining the size of the

feed pump, by taking the number of square feet of heating surface in the boiler and allow a pump capacity of 1 cu. ft. per hour for each 15 sq. ft. of heating surface. Thus, let the total heating surface of the boiler be 786 sq. ft. Dividing this by 15 gives 52.4 as the number of cubic feet of water required per hour, from which the pump dimensions may be found in the same way as in the preceding case.

In figuring on the capacity of a feed pump for a battery of two or more boilers, the total quantity of water required by all the boilers must be taken into consideration. All boiler-rooms should be supplied with at least two feed pumps, so that if one breaks down there may always be another one available.

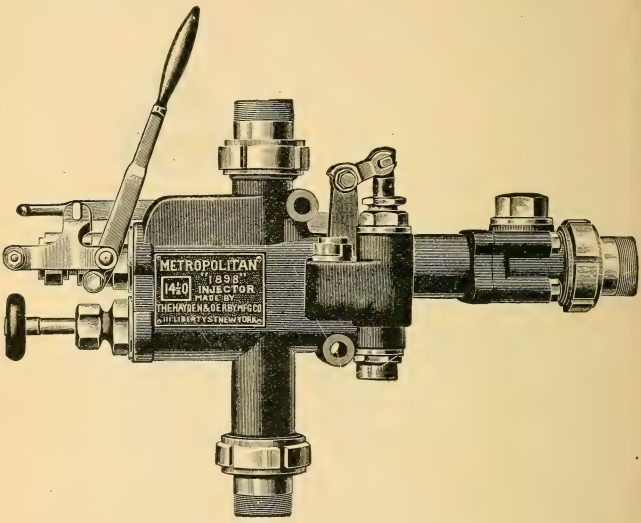


U. S. AUTOMATIC INJECTOR.

The injector is a reliable boiler feeder, and is in fact more economical than the steam pump, because the heat in the steam used is all returned to the boiler, excepting the losses by radiation. But the disadvantage attending the use of the injector is that it will not work well with the feed water at a temperature very much in excess of 100° F., while a good steam pump, fitted with hard rubber valves, will handle water at a temperature as high as 200° or 208° F., when the water flows to the pump by gravity from a heater, or it will raise water from a receiving tank on a short suction lift at a temperature of 150° or 160° F.

Feed Water Heaters. One great source of economy

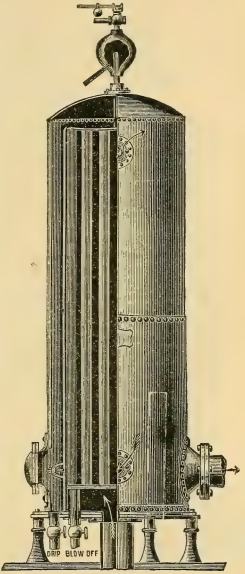
in fuel is the utilization of all the available exhaust steam for heating the feed water before it enters the boiler. Of course if the main engine is a condensing engine, the exhaust from that source is not directly available, except by interposing a closed heater between the cylinder and the condenser, or by using



METROPOLITAN INJECTOR, MODEL O.

the water of condensation for feeding the boilers. This can be done with safety, provided a surface condenser is used, but with a jet condenser or an open heater in which the exhaust mingles with the water, it is advisable to have an oil separator to prevent the oil from getting into the boilers.

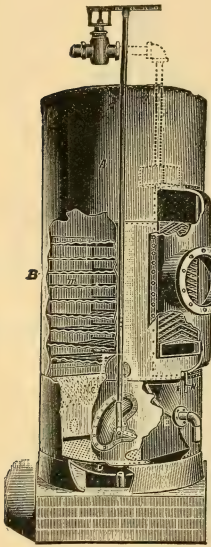
Exhaust heaters are of two kinds, open and closed. In the open heater the exhaust steam mingles directly with the water and a portion of it is condensed. A well-designed open exhaust heater will raise the temperature of the water to very nearly the boiling point, 212° F. These heaters should be set so that the water will flow by gravity from them to the feed pump In the closed type of exhaust heaters, the exhaust steam and the water are kept separate. In some styles the steam passes through tubes, which are surrounded by water, while in others the water fills the tubes, which are in turn surrounded by the steam. In either case the water in the closed heater is under the full boiler pressure while the feed pump is in operation, because the heater is between the pump and the boiler, while with the open heater the pump is between the heater and the boiler.



BARAGWANATH STEAM JACKET FEED WATER HEATER.

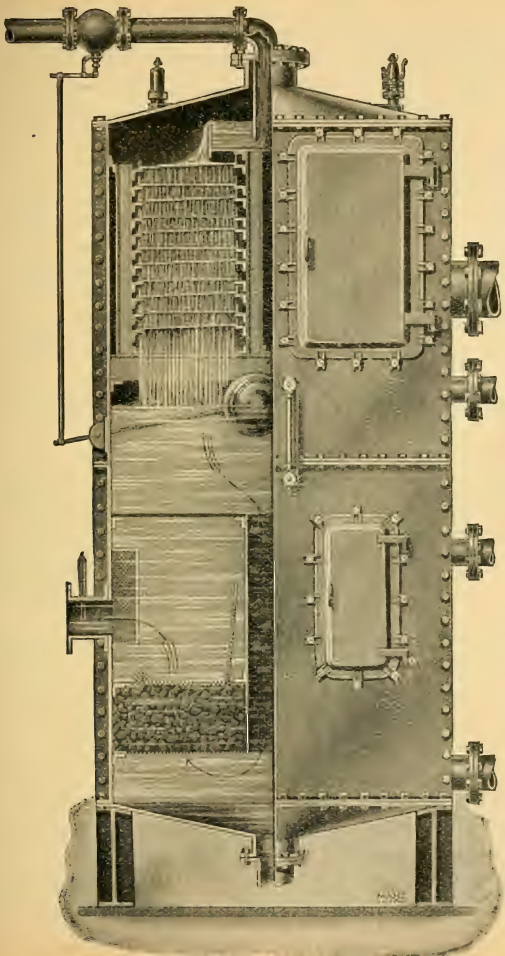
The saving effected by heating the feed water with exhaust steam can be easily ascertained by the use of a thermometer, a steam table, and a simple arithmetical calculation. First, find by thermometer the temperature of the water before entering the heater; find its temperature as it leaves the heater. Next ascertain by

the steam table the number of heat units above 32° F. in the water at each of the two temperatures. Subtract the less from the greater, and the remainder will be the number of heat units added to the water by the heater. Next find by the table the number of heat units above 32° F. in the steam at the pressure ordinarily carried in the boiler, and subtract from this the number of heat units in the water before it enters the heater. The result will be the number of heat units that would be required to convert the water into steam of the required pressure, provided no heater were used. Then to find the percentage of saving effected by the heater, multiply the number of heat units added to the water by the heater by 100, and divide by the number of heat units required to convert the unheated water into steam, from the initial temperature at which it enters the heater.



INTERIOR VIEW OF OPEN HEATER.

Example. Assume the boiler to be carrying 100 lbs. gauge pressure. Suppose the temperature of the water before entering the heater is 60° F., and that after leaving the heater its temperature is 202° F., what is the percentage of saving due to the heater? The solution of the problem is as follows:



Boiler pressure by gauge = 100 lbs.

Initial temperature of feed water = 60° F.

Heated temperature of feed water = 202° F.

From the steam table (see Chapter IV., Table 5) it is found that

Heat units in water at 202° F. = 170.7.

Heat units in water at 60° F. = 28.01.

Heat units added to water by heater = 170.7 − 28.01 = 142.69.

Heat units in steam at 100 lbs. gauge pressure = 1185.0.

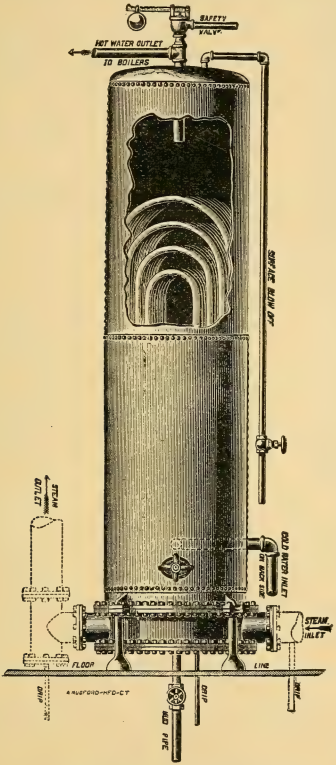
Heat units to be added to water at 60° F. to make steam of 100 lbs. gauge pressure = 1185.0 − 28.01 = 1156.99.

Percentage of saving effected by the use of the heater = $\frac{142.69 \times 100}{1156.99}$ = 12.33 per cent.

Suppose the coal consumed under this boiler amounts to two tons per day at a cost of $3.00 per ton, or a fuel cost of $6.00 per day. Then the saving in dollars and cents due to the heater in the foregoing example would be 12.33 per cent of $6.00, or $0.7398 (74 cents) per day.

Heaters, especially those of the closed type, should have capacity sufficient to supply the boiler for fifteen or twenty minutes. There would then be a body of water continually in the heater in direct contact with the heating surface, and as it passes slowly through it will receive much more heat than if rushed through a heater that is too small. All heaters and feed pipes should be well protected by some good insulating covering to prevent loss of heat by radiation. In some cases the exhaust steam, or a portion of it at least, can be used to advantage in an exhaust injector.

This device, where it can be used at all, is economical in that it not only feeds the boiler, but also heats the



CLOSED FEED WATER HEATER.

water without the use of live steam. But it will not force the water against a pressure much above 75 lbs.

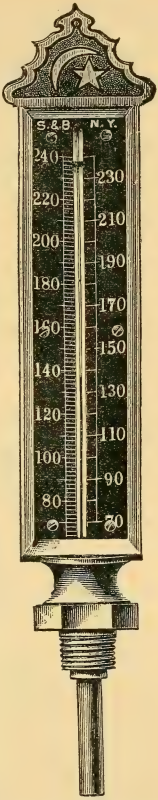
to the square inch, and if the initial temperature of the water is much above 75° F. the exhaust injector will not handle it. Heaters which use live steam direct from the boilers heat the feed water to a much higher temperature, so that they act as purifiers by removing a large portion of the scale-forming impurities before the water enters the boiler. Live steam heaters, however, are not to be considered as economizers of heat.

Provisions for Testing. While considering feed pipes and other apparatus necessarily appertaining to the feeding of boilers, it is well to devote a short space also to the fittings and other devices required for successfully conducting tests of the boiler and furnace. This subject is mentioned here for the reason that the author considers that the necessary fittings and appliances for making evaporative tests properly belong to, and in fact are a part of, the feed piping, and can be put in while the plant is being erected at much less cost and trouble than if the matter is postponed until after the plant is in operation.

Beginning then at the check valve, there should be a tee located in the horizontal section of the feed pipe, as near to the check valve as practicable, and between it and the feed pump; or a tee can be used in place of an ell to connect the vertical and horizontal sections of the branch pipe where it rises in front of the boiler. One opening of this tee is reduced to ⅜ or ½ in. to permit the attachment of a hot water thermometer. These thermometers are also made angle-shaped at the shank, so that if desired they can be screwed into a tee placed in vertical pipe and still allow the scale to stand vertical. The thermometer is for the purpose of showing at what temperature the feed water enters

the boiler during the test, and therefore should be as near the boiler as possible. After the test is completed the thermometer may be taken out and a plug inserted in its place.

The next requirement will be a device of some kind for ascertaining the weight of water pumped into the boiler during the test. In some well ordered plants each boiler is fitted with a hot water meter in the feed pipe, but as this arrangement is hardly within the reach of all, a substitute equally as accurate can be made by placing two small water tanks, each having a capacity of eight or ten cubic feet, in the vicinity of the feed pump. These tanks can be made of light tank iron, and each should be fitted with a nipple and valve near the bottom for connection with the suction side of the pump. The tops of the tanks may be left open. If an open heater is used, and it is possible to place the tanks low enough to allow a portion of the water from the heater to be led into them by gravity, it will be desirable to do so. A pipe leading from the main water supply, with a branch to each tank, is also needed for filling them. One of the feed pumps, of which there should always be at least two, as already stated, is fitted with a tee in the suction pipe near the pump to receive the pipe



HOT WATER THERMOMETER.

leading from the tanks. During the test the main suction leading to this pump from the general supply should be kept closed, so that only the water that passes through the tanks is used for feeding the boiler. If the plant be a small one, with but one or two boilers and only a single feed pump, the latter can be made to do duty as a testing pump, because during the test there will be no other boilers to feed besides the ones under test.

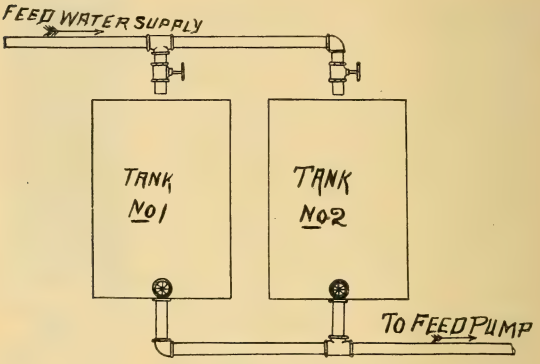


FIGURE 10.

If metal tanks are considered too expensive, two good water-tight barrels can be substituted. Fig. 10 will give the reader a general idea of what is needed for obtaining the weight of the water by the method just described. If a closed heater is used and no other boilers are in service during the test, the cold water can be measured in the tanks and pumped directly through the heater, but if it is necessary to feed other boilers besides those under test, then either a separate

feed pipe must be run to the test boilers, or else hot water meters will have to be put into the branch pipes.

In cases where a separate feed pipe must be put in for the test boiler and the water which is used for testing cannot be passed through a heater, there should be a ¾ or 1 in. pipe connected to the feed main or header and leading to the testing tanks, in order to allow a portion of the hot feed water to run into and mix with the cold water in the tanks as they are being filled, thus partially warming the water before it goes to the boiler.

Heating Surface. The heating surface of a boiler consists of that portion of the boiler which is exposed to the heat on one side and water on the other. In a horizontal boiler of either the flue or tubular type, the available heating surface is, first, the lower half of the shell; second, the area of the back head below the water line minus the combined cross sectional area of all the tubes or flues; third, the inside area of the flues; fourth, the area of the front head minus the sectional area of the flues.

For a fire-box boiler of the vertical type, the area of the flue sheets minus the sectional area of the flues, plus the area of the fire-box plus the inside area of the flues constitutes the heating surface. If the boiler is a horizontal internally fired boiler, the heating surface will consist of, first, area of three sides of the fire-box; second, area of the crown sheet; third, area of flue sheets minus sectional area of flues; fourth, inside area of the flues.

In estimating the area of the fire-box, the area of the fire door should be subtracted therefrom. If the fire-box be circular, as in the case of a vertical boiler, the area may be obtained by first finding by measurements

the diameter, which multiplied by 3.1416 will give the circumference. Then multiply this result by the height or the distance between the grate bars and the flue sheet. In the case of water tube boilers the outside area of the tubes must be taken. Two examples will be given illustrating methods of calculating heating surface:

First, take a horizontal tubular boiler, diameter 72 in., length 18 ft., having sixty-two 4½ in. flues; find area of lower half of shell.

Circumference = diameter × 3.1416 = 18.8496 ft.

One-half of the circumference multiplied by the length = required area. Thus, 18.8496 ÷ 2 × 18 = 169.64 sq. ft.

Next find heating surface of back head below the water line. Total area = $72^2 \times .7854 = 4071.5$ sq. in. Assume two-thirds of this area to be exposed to the heat. ⅔ of 4071.5 = 2714.3 sq. in. From this must be deducted the sectional area of the tubes. In giving the size of boiler tubes the outside diameter is taken. The tubes being 4½ in.; the area of a circle 4½ in. in diameter is 15.9 sq. in. Number of flues, 62 × 15.9 = 985.8 sq. in. = sectional area of tubes. The heating surface of the back head therefore = 2714.3 − 985.8 = 1728.5 sq. in. Dividing this by 144, to reduce to feet, we have 12 sq. ft.

Next find inside area of tubes. The standard thickness of a 4½ in. tube = .134 in. The inside diameter therefore will be 4.5 − (2 × .134) = 4.23 in., and the circumference will be 4.23 × 3.1416 = 13.29 in., and the inside area will be 13.29 × length, 18 ft., = 216 in. Thus 216 × 13.29 ÷ 144 = 19.93 sq. ft., inside area of one flue. There being 62 flues, the total heating surface of tubes is 19.93 × 62 = 1235.66 sq. ft. The heating sur-

face of the front head is found in the same manner as that of the back head, with the exception that the whole area should be figured instead of two-thirds, for the reason that the entire surface is exposed to the heat, although that portion above the water line may be considered as superheating surface. The heating surface of front head would be: area 4071.5 – sectional area of tubes 985.8 = 3085.7 sq. in. = 21.43 sq. ft.

The total heating surface of the boiler is thus found to be 1438.73 sq. ft, divided up as follows:

Lower half of shell,	169.64	sq. ft.
Back head,	12.00	"
Tubes,	1235.66	"
Front head,	21.43	"
	1438.73	"

Next taking a vertical fire-box boiler of the following dimensions: diameter of flue sheet, and also of fire-box, 50 in.; height of fire-box above grate bars, 30 in.; number of flues, 200; size of flues, 2 in.; length of flues, 7 ft.

First, find heating surface in flue sheet.

Area of circle, 50 in. in diameter = 1,963.5 sq. in.

Sectional area of 2 in. flue = 3.14 sq. in., which multiplied by 200 = 628 sq. in., total sectional area of tubes. The heating surface of one flue sheet therefore will be 1,963.5 – 628 ÷ 144 = 9 sq. ft.

Assuming that the tops of the flues are submerged, the area of the top flue sheet will also be 9 sq. ft. Then heating surface of flue sheets = 9 × 2 = 18 sq. ft.

Second, find heating surface of tubes. The standard thickness of a 2 in. flue is .095 in. The inside diameter will consequently be 2 – (.095 × 2) = 1.8 in., and the circumference will be 1.8 × 3.1416 = 5.66 in. The

length of the flue being 7 ft., or 84 in., the inside area will be $5.66 \times 84 \div 144 = 3.3$ sq. ft., and multiplying this result by 200 we have $200 \times 3.3 = 660$ sq. ft. as the heating surface of the flues.

Third, find heating surface of the fire-box. Diameter of fire-box = 50 in., which multiplied by $3.1416 = 157.08$, which is the circumference. The height being 30 in., the total area will be $157.08 \times 30 \div 144 = 32.7$ sq. ft. Allowing 1 sq. ft. as the area of the fire door, will leave 31.7 sq. ft. heating surface of fire-box. The heating surface of the boiler will be:

For the flue sheets,	18	sq. ft.
For the flues,	660	"
For the fire-box,	31.7	"
Total,	709.7	"

The above methods may be applied in estimating the heating surface of any boiler, provided in the case of water tube boilers that the outside in place of the inside area of the tubes be figured.

Questions

1. How should the bridge wall of a horizontal boiler be built?

2. How should the brick work of a boiler be secured in order to prevent damage by expansion and contraction?

3. Which end of a horizontal boiler should be the lowest, and why?

4. How should the water column be located?

5. How high above the top row of tubes should the lower gauge cock be?

6. What is the proper ratio of safety valve area to grate surface?

7. Where should the fusible plug be located?

8. Where should the feed pipe enter the boiler?

9. Where should the blow off pipe be connected?

10. What is the most economical device for feeding a boiler?

11. In selecting a feed pump, how may the required size of pump be ascertained?

12. What is the disadvantage in the use of the injector for feeding a boiler?

13. What is gained by using a feed water heater?

14. How many kinds of exhaust heaters are there?

15. How may the saving effected by using the exhaust steam for heating the feed water be estimated?

16. What should the capacity of the heater be?

17. What provision should be made for testing coal and other fuel?

18. What is the heating surface of a boiler?

CHAPTER III

BOILER OPERATION

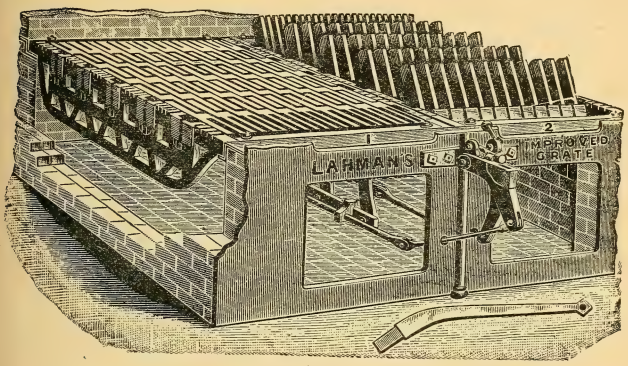
First care of the engineer on entering his boiler-room—Cleaning fires—Fire tools, etc.—Firing—Suggestions as to best method of firing—Quantity of air required per pound of coal—Cleaning tubes—Washing out, etc.—Why it is dangerous to cool a boiler too quickly—Repairing tubes—Cleaning inside of boiler—Pitting—How to feed a boiler—What to do in cases of emergency—Connecting with main—Foaming, priming, etc.—Safety valve calculations—Rules for safety valve calculations—Feed pumps—Care of feed pumps—Directions for setting steam valves of duplex pumps—Hydraulics for engineers.

Operation. Having considered in the previous chapters the principal details in the construction and erection of boilers with which the working engineer is interested, it is now in order to devote a space to their operation.

Duties. The first act of the careful engineer on entering his boiler-room when he goes on duty should be to ascertain the exact height of the water in his boilers. This he can do by opening the valve in the drain pipe of the water column, allowing it to blow out freely for a few seconds, then close it tight and allow the water to settle back in the glass. This should be done with each boiler under steam, not only once, but several times during the day. No engineer should be satisfied with a general squint along the line of gauge glasses, but he should either go himself or else instruct his fireman or water tender to make the rounds of each boiler and be sure that the water is all right.

The next thing to be looked after is the fire. If the plant is run continuously day and night it is the duty of the firemen coming off watch to have the fires clean, the ash pits all cleaned out, a good supply of coal on the floor, and everything in good order for the on coming force. A good fireman will take pride in always leaving things in neat shape for the man who is to relieve him.

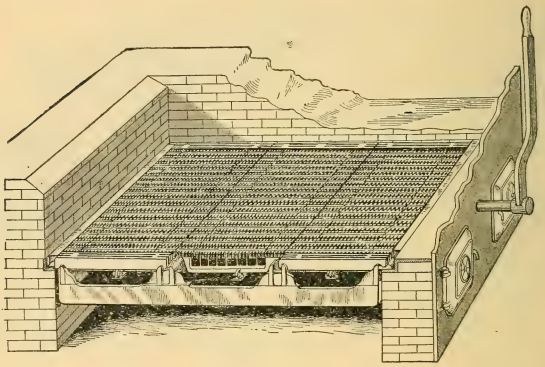
Cleaning Fires. With some varieties of coal this is



LAHMAN'S GRATE.

a comparatively easy task, especially if the boilers are fitted with shaking grates. With a coal that does not form a clinker on the grate bars, the fires can be kept in good condition by cleaning them twice or three times in twenty-four hours, as the larger part of the loose ashes and noncombustible can be gotten rid of by shaking the grates and using the slice bar at intervals more or less frequent; but such coals are generally considered too expensive to use in the ordinary manufacturing plant, and cheaper grades are substituted.

Fire Tools. For cleaning fires successfully and quickly the following tools should be provided: a slice bar, a fire hook, a heavy iron or steel hoe, and a light hoe for cleaning the ash-pit. It is unnecessary to describe these tools, as they are familiar to all engineers. A suggestion as to the kind of handles with which they should be fitted may be of benefit. The working ends of the aforesaid tools having been made and each welded to a bar of 1 or 1⅛ in. round



MARTIN ANTI-FRICTION ROCKING GRATES.

iron and 10 or 12 in. long, take pieces of 1 or 1¼ in. iron pipe cut to the length desired for the handles and weld the shanks of the tools to them. To the other end of the pipe weld a handle made of round iron somewhat smaller than the shank. By using pipe handles the weight of the tools is considerably lessened, and they will still be sufficiently strong. The labor of cleaning the fire will thus be greatly lightened. When a fire shows signs of being foul and choked with

clinker, preparations should be made at once for cleaning it by allowing one side to burn down as low as possible, putting fresh coal on the other side alone. When the first side has burned as low as it can without danger of letting the steam pressure fall too much, take the slice bar and run it in along the side of the furnace on top of the clinker and back to near the bridge wall, then using the door jamb as a fulcrum, give it a quick strong sweep across the fire and the greater part of the live coals will be pushed over to the other side. What remains of the coal not yet consumed can be pulled out upon the floor with the light hoe and shoveled to one side, to be thrown back into the furnace after the clinker is taken out. Having now disposed of the live coal, take the slice bar and run it along on top of the grates, loosening and breaking up the clinker thoroughly, after which take the heavy hoe and pull it all out on the floor. A helper should be ready with a pail of water, or, what is still better, a small rubber hose connected to a cold water pipe running along the boiler fronts for this purpose, and put on just enough water to quench the intense heat of the red hot clinker as it lies on the floor. When the grates are cleaned, close the door, and with the slice bar in the other side push all the live coal over to the side just cleaned, where it should be leveled off and fresh coal added. After this has become ignited, treat the other side in the same way. An expert fireman will thus clean a fire with very little loss in steam pressure, and practically no waste of coal.

Firing. No definite set of rules for hand firing can be laid down that will be suitable for all steam plants, or for the many different kinds of coal used. Some kinds of coal need very little stirring or slicing, while

others that have a tendency to coke and form a crust on top of the fire need to be sliced quite often.

Every engineer, if he is at all observant, should be able to judge for himself as to the best method of treating the coal he is using, so as to get the most economical results. A few general maxims may be laid down. First, keep a clean fire; second, see that every square inch of grate surface is covered with a good live fire; third, keep a level fire, don't allow hills and valleys and yawning chasms to form in the furnace, but keep the fire level; fourth, when cleaning the fire always be sure to clean all the clinkers and dead ashes away from the back end of the grates at the bridge wall, in order that the air may have a free passage through the grate bars, because this is one of the best points in the furnace for securing good combustion provided the bridge wall is kept clean from the grates up. By keeping the back ends of the grate bars and the face of the bridge wall clean, the air is permitted to come in contact with the hot fire brick, and thus one of the greatest aids to good combustion is utilized. Don't allow the fire to become so deep and heavy that the air cannot pass up through it, because without a good supply of air good combustion is impossible. When the chimney draft is good the quantity of cold air admitted underneath the grate bars may be easily regulated by leaving the ash-pit doors partly open. The amount of opening required can be ascertained by a little experimenting and depends upon the intensity of the draft and the condition of the fire. With a clean, light fire and the air spaces in the grates free from dead ashes, a slight opening of the ash-pit doors will suffice to admit all the air required beneath the grates. But if the fire is

heavy and the grates are clogged, a larger opening will be necessary. In firing bituminous coal containing a large percentage of volatile (light or gaseous matter) the best results can be obtained by leaving the fire doors slightly open for a few seconds immediately after throwing in a fresh fire. The reason for doing this is that the volatile matter in the coal flashes into flame the instant it comes in contact with the heat of the furnace, and if a sufficient supply of oxygen is not present just at this particular time the combustion will be imperfect and the result will be the formation of carbon mon-oxide or carbonic oxide gas, and the loss of about two-thirds of the heat units contained in the coal. This loss can be guarded against in a great measure by a sufficient volume of air, either through the fire doors directly after putting in a fresh fire, or, what is still better, providing air ducts through the bridge wall or side walls which will bring the air in on top of the fire. Each pound of coal requires for its complete combustion 12 lbs. or about 150 cu. ft. of air, and the largest volume of air is needed just after fresh coal has been added to the fire.

Cleanliness. In order to get the best results great care should be taken that the tubes be kept clean and free from soot. Especially does this apply to horizontal return tubular boilers, for the reason that when the tubes become clogged with soot the efficiency of the draft is destroyed and the steaming capacity of the boiler is greatly reduced. Soot not only stops the draft, but it is a non-conductor of heat. In some batteries of boilers where an inferior grade of coal is used and the draft is poor, it is absolutely necessary to scrape or blow the tubes at least once a day in order to enable the boilers to generate sufficient steam.

As to the process of cleaning there are various devices on the market, both for blowing the soot out by means of a steam jet and also for scraping the inside of the tubes. The steam jet, if properly made and used with a high pressure and dry steam, does very satisfactory work, but it should not be depended upon exclusively to keep the tubes clean, because in process of time a scale will form inside the tubes that nothing but a good scraper will remove. For that reason it is good practice to use the scraper two or three times a week at least. When the boiler is cooled down for washing out, the bottom of the shell should be cleaned of all accumulations of dust and ashes, the combustion chamber back of the bridge wall cleaned out, and the back flue sheet or head swept off and examined, and if there is a fusible plug in the back head the scale should be scraped from it, both inside and outside the boiler, because if it is covered with scale neither the water nor the heat can come in contact with it, and it will be non-effective.

Washing Out. The length of time that a boiler can be run safely and economically after having been washed out depends upon the nature of the feed water. If the water is impregnated to a considerable extent with scale forming matter, the boiler should be washed out every two weeks at the least, and in some cases of particularly bad water it becomes necessary to shorten the time to one week. To prepare a boiler for washing the fire should be allowed to burn as low as possible and then be pulled out of the furnace, the furnace doors left slightly ajar and the damper left wide open in order that the walls may gradually cool. It is as bad a practice to cool a boiler off too suddenly as it is to fire it up too quick, because the sudden change of

temperature either way has an injurious effect on the seams, contracting or expanding the plates, according as it is cooled or warmed, and thus creating leaks and very often small cracks radiating from the rivet holes, and becoming larger with each change of temperature, until finally the strength of the seam is destroyed and rupture takes place. After the boiler has become comparatively cool and there is no pressure indicated by the steam gauge the blow off cock may be opened and the water allowed to run out. The gauge cocks and also the drip to the water column should be left open to allow the air to enter and displace the water. Otherwise there will be a partial vacuum formed in the boiler and the water will not run out freely.

A boiler should not be blown out, that is, emptied of water while under pressure. The sudden change of temperature is sure to have a bad effect upon the sheets and seams. Suppose for instance that all the water is blown out of a boiler under a pressure of 20 lbs. by the steam gauge. The temperature of steam at 20 lbs. is 260° F., and it may be assumed that the metal of the boiler is at or near that temperature also. Assume the temperature of the atmosphere in the boiler-room to be 60° F. There will then be a range of $260° - 60° = 200°$ temperature for the boiler to pass through within a short time, which will certainly have a bad effect, and besides this the boiler shell will be so hot that the loose mud and sediment left after the water has run out is liable to be baked upon the sheets, making it much harder to remove.

While inside the boiler the boiler washer should closely examine all the braces and stays, and if any are found loose or broken they should be repaired at once before the boiler is used again. The soundness of

braces, rivets, etc., can be ascertained by tapping them with a light hammer.

Renewing Tubes. As it is practically impossible to prevent scale from forming on the outside of the tubes of horizontal tubular boilers unless the feed water is exceptionally good, and as the tubes will in course of time become leaky where they are expanded into the heads, the engineer if he has a battery of two or more, should take advantage of the first opportunity that presents itself to take out of service the boiler that shows the most signs of deterioration and take out the tubes, and after cleaning them of scale by scraping and hammering or rolling in a tumbling cylinder, he should select those that are still in good condition and have them pieced out at the ends, making them almost as good as new.

The flues being out of the boiler will give the boiler washer a good opportunity to thoroughly clean the inside also, and if there are any loose rivets they should be replaced and leaky or suspicious looking seams chipped and caulked. If there are indications of corrosion or pitting, a stiff paste or putty made of plumbago mixed with a small proportion of cylinder oil may be applied to the affected parts with good results.

Feed Water. There is no steam plant of any consequence that does not have more or less exhaust steam or returns from a steam heating system which can be utilized for heating the feed water before it enters the boiler. Cold water should never be pumped into a boiler that is under steam when it is possible to prevent it.

In feeding a boiler the speed of the feed pump should be so gauged as to supply the water just as fast

as it is evaporated. The firing can then be even and regular.

If the supply of feed water should suddenly be cut off, owing to breakage of the pump or bursting of a water main, and no other source of supply was available, the dampers should be immediately closed, or if there should be no damper in the breeching, the draft may be stopped by opening the flue doors. The fires should then be deadened by shoveling wet or damp ashes in on top of them, or if the ashes cannot be readily procured, bank the fires over with green coal broken into fine bits. This, with the draft all shut off, will deaden the fires, while the engine still running will gradually use up the extra steam. If the water should get dangerously low in the boilers the fires may be pulled, provided they have become deadened sufficiently, but they should never be pulled while they are burning lively, because the stirring will only serve to increase the heat and the danger will be aggravated.

Connecting a Recently Fired Up Boiler. After a boiler has been washed out, filled with water, and fired up, the next move is to connect it with the main battery. The steam in the boiler to be connected having been raised to the same pressure as that in the battery, the connecting valve should be opened slightly, just enough to permit a small jet of steam to pass through, which can be heard by placing the ear near the body of the valve. This jet of steam may be passing from the battery into the newly connected boiler or *vice versa.* Whichever way it passes, the valve should not be opened any farther until the flow of steam stops, which will indicate that the pressure has been equalized. It will then be found that the valve will move

much easier and it may be gradually opened until it is wide open.

Foaming. Water carried with the steam from the boiler to the engine, even if in small quantities, is very detrimental to the successful operation of the engine, as it washes the oil from the walls of the cylinder, thereby increasing the friction, and unless a plentiful supply of oil is entering the cylinder cutting of the piston rings will take place. There is also danger of breaking a cylinder head or of bending the piston rod if the water comes in too large quantities.

There are certain kinds of water which have a natural tendency to foam, especially such as contain considerable organic matter, and the more severe the service to which the boiler is put the more will the water foam, until it is practically impossible to locate the true level of the water in the boilers, and the only recourse the water tender has is to keep his feed pump running at such a speed as will in his judgment supply the water as fast as it goes out of the boilers. It is a dangerous condition to say the least, and the only remedy for it is either a change to a different kind of water, or if this is not possible, then an increase in the number of boilers, which would make it possible to supply sufficient steam for the engine without being compelled to fire the boilers so hard.

Priming. By which is meant the carrying over of water in the form of fine spray mingled with the steam, is not so dangerous as foaming and yet it causes much loss in the efficiency of a boiler or engine. It can be prevented to a large extent by placing a baffle plate in the steam space of the boiler directly under the dome or outlet to the connection with the steam main.

Safety Valves. Rules are given in Chapter II. for guidance in making calculations relating to spring pop valves, which are now almost universally used on boilers, and which, without doubt, are the most reliable appliance for relieving a boiler of surplus steam.

A short space will be devoted to the consideration of the lever safety valve also, as it may be of interest to some students.

The U. S. marine rule for lever valves is here repeated: "Lever safety valves to be attached to marine boilers shall have an area of not less than one square inch to every two square feet of grate surface in the boiler, and the seats of all such safety valves shall have an angle of inclination of 45° to the center line of their axis."

In order to arrive at accurate results in lever safety valve calculations it is necessary to know first the number of pounds pressure exerted upon the stem of the valve by the lever itself, irrespective of the weight, also the weight of the valve and stem, as all these weights together with the weight of the ball suspended upon the lever tend to hold the valve down against the pressure of the steam. The effective weight of the lever can be ascertained by leaving it in its position attached to the fulcrum and connecting a spring balance scale to it at the point where it rests on the valve stem. The weight of the valve and stem can also be found by means of the scale. When the above weights are known, together with the weight at the end of the lever and its distance from the fulcrum, also the area of the valve and its distance from the fulcrum, the pressure at which the valve will blow can be found by the following rules:

Rule 1. Multiply the weight by its distance from the

fulcrum. Multiply the weight of the valve and lever by the distance of the stem from the fulcrum and add this to the former product. Divide the sum of the two products by the product of the area of the valve multiplied by the distance of its stem from the fulcrum. The result will be pressure in pounds per square inch required to lift the valve.

Example. Diameter of value, 3 in.

Distance of stem from fulcrum, 3 in.

Effective weight of lever, valve and stem, 20 lbs.

Weight of ball, 50 lbs.

Distance of ball from fulcrum, 30 in.

Required pressure at which the valve will blow off, $50 \times 30 + 20 \times 3 = 1560$.

Area of valve, $7.0686 \times 3 = 21.2058$.

$1560 \div 21.2058 = 73.57$ lbs. pressure.

When the pressure at which it is desired the valve should blow off is known, together with the weights of all the parts, the proper distance from the fulcrum at which to place the weight is ascertained by Rule 2.

Rule 2. Multiply the area of the valve by the pressure and from the product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of the stem from the fulcrum and divide by the weight of the ball. The quotient will be the required distance.

Example. Area of valve, 7.07 sq. in.

To blow off at 75 lbs.

Effective weight of lever and valve, 20 lbs.

Weight of ball, 50 lbs.

Distance of valve stem from fulcrum, 3 in.

$7.07 \times 75 - 20 = 510.25$.

$510.25 \times 3 \div 50 = 30.6$ in., distance from fulcrum at which to place the ball.

When the pressure is known, together with the distance of the weight from the fulcrum, the weight of the ball is obtained by Rule 3.

Rule 3. Multiply the area of the valve by the pressure and from the product subtract the effective weight of the lever and valve. Multiply the remainder by the distance of the stem from the fulcrum and divide by the distance of the ball from the fulcrum. The quotient will be the required weight.

Example. Area of valve, ... 7.07 sq. in.
Pressure in pounds per square inch, . . 80 lbs.
Effective weight of lever and valve, . . 20 lbs.
Distance of stem from fulcrum, ... 3 in.
Distance of weight from fulcrum, . . . 30 in.
$7.07 \times 80 - 20 = 545.6$.
$545.6 \times 3 \div 30 = 54.56$ lbs., weight of ball.

Safety valves, especially those of the lever type, are liable to become corroded and stick to their seats if allowed to go any great length of time without blowing. Therefore it is good practice to raise the steam pressure to the blowing off point at least two or three times a week, or oftener, for the purpose of testing the valve. If it opens and releases the steam at the proper point all is well, but if it does not, it should be looked after forthwith. Generally the mere raising of the lever by hand, or a few taps with a hammer if it be a pop valve, will free it and cause it to work all right again; but if this treatment has to be resorted to very often the valve should be taken down and overhauled. In too many steam plants not enough importance is attached to the safety valve. The fact is, it is one of the most useful and important adjuncts of a boiler, and if neglected serious results are sure to follow.

Feed Pumps. A good engineer will always take a pride in keeping his feed pump in good condition, and if he has two or more of them, which every steam plant of any consequence should have, he will have an opportunity to keep his pumps in good shape. The water pistons of most boiler feed pumps are fitted to receive rings of fibrous packing. The best packing for this purpose and one that will stand both hot and cold water service is made of pure canvas cut in strips of the required width, ½, ⅝, ¾ in., etc., and laid together with a water proof cement having the edges for the wearing surface. This packing is called square canvas packing, and can be purchased in any size required for the pump. The size is easily ascertained by placing the water piston, minus the follower plate, centrally in the water cylinder and measuring the space between the piston and cylinder walls. This packing should not be allowed to run for too long a time before renewing, for the reason that pieces of it are liable to become loose and be forced along with the feed water on its way to the boiler and lodge under the check valve, holding it open and causing no end of trouble. If the feed pump has to handle hot water, or has to lift the water several feet by suction, the packing rings should be looked after at least once a month.

Hard rubber valves are, all things considered, the best for a boiler feed pump, as they are not affected by hot water and do not hammer the seats like metallic composition valves do. Every boiler feed pump should be fitted with a good sight-feed lubricator for cylinder oil. The steam valve mechanism of a steam pump is very sensitive and delicate and requires good lubrication in order to do good work. In too many

cases feed pumps are fitted with an old style cylinder oil cup and there is generally more oil on the outside of the valve chest than there is inside, while the valve is bulldozed into working by frequent blows from a convenient club.

The steam valves of all steam pumps are adjusted before they are sent out from the factory, and most of them are arranged so that the stroke may be shortened or lengthened as the engineer desires. It is best as a rule to allow a pump to make as long a stroke as it will without striking the heads, because then the parts are worn evenly.

Sometimes an engineer is called upon to set the valves of a duplex pump which have become disarranged. In such a case he should proceed as follows: Place both pistons exactly at mid-stroke. This may be done in two ways. First, by dropping a plummet line alongside the levers connecting the rock shafts with the spools on the piston rods. Then bring the rods to the position where the centers of the spools will be in a vertical line with the centers of the rock shafts.

The second method is to move the piston to the extreme end of the stroke until it comes in contact with the cylinder head. Then mark the rod at the face of the stuffing box gland. Next move the piston to the other end of the stroke and mark the rod at the opposite gland. Now make a mark on the rod exactly half way between the two outside marks and move the piston back until the middle mark is at the face of the gland and the piston will be at mid-stroke. Having placed both pistons at mid-strike, remove the valve chest covers and adjust the valves in their central position, viz., so that they cover the steam ports. The

valve rod being in position and connected to the rocker arm by means of the short link, the nut or nuts securing the valve to the rod should be so adjusted as to be equidistant from the lugs on the valve, say $\frac{3}{32}$ or $\frac{1}{8}$ of an inch according to the amount of lost motion desired, which latter factor governs the length of stroke in some makes of duplex pumps, while in others it is controlled by tappets on the valve rod outside of the valve chest. Care should be taken while making these adjustments that the valve be retained exactly in its central position.

Having set the valves correctly, move one of the pistons far enough from mid-stroke to get a small opening of the steam port on the opposite side, then replace the valve chest covers and the pump will be ready to run. As these valves are generally made without any outside lap, a slight movement of one of the pistons in either direction from its central position will suffice to uncover one of the ports on the other cylinder sufficiently to start the pump.

Sometimes duplex pumps "work lame," that is, one piston will make a quick full stroke while the other piston will move very slowly and just far enough to work the steam valve of the opposite side. In the majority of cases this irregular action is due to unequal friction in the packing of the rods, or the packing rings on one of the pistons may be worn out.

If one side of a duplex pump becomes disabled from any cause, as breaking of piston rod in the water cylinder, for instance, which is liable to happen, the pump may still be operated in the following manner until duplicate parts to replace the broken ones have been secured. Loosen the nuts or tappets on the valve stem of the broken side and place them far

enough apart so that the steam valve will be moved through only a small portion of its stroke, thereby admitting only steam enough to move the empty steam piston and rod, and thus work the steam valve of the remaining side. The packing on the broken rod should be screwed up tight, so as to create as much friction as possible; there being no resistance in the water end. In this way the pump may be operated for several days or weeks and thus prevent a shut down.

Hydraulics for Engineers. Among the many difficult problems that are continually coming up for engineers to solve, there is none more perplexing than the correct calculation of the quantity of water which will be discharged in a given time from pipes of various sizes and under the many different heads or pressures. Problems in hydraulics, as given by the majority of writers on engineering, are usually in elaborate algebraical equations, which, to the ordinary working engineer, are very perplexing, at least the author has found them to be so in his experience. Therefore with a view of assisting his brother engineers in the solution of problems along this line which they may be called upon to solve, the author has spent considerable time and labor in searching for and compiling a few rules and examples for hydraulic calculations in plain arithmetic which he hopes may be of benefit.

First, to find velocity of flow in the pump, or in other words, piston speed.

Rule. Multiply number of strokes per minute by length of stroke in feet, or fractions thereof.

Second, the velocity of flow in the discharge pipe is in inverse ratio to the squares of the diameters of the pipe and the water cylinder of pump.

Thus, a pump cylinder is 6 in. in diameter, and the piston speed is 100 ft. per minute; the discharge pipe being 3 in. in diameter. What is the velocity of flow in the pipe?

Example. $\frac{6\times6}{3\times3}=4$. In this case the velocity in the pipe is four times that in the pump, and $100\times4=400$ ft. per minute, velocity for water in the discharge pipe.

Third, to find velocity in feet per minute necessary to discharge a given quantity of water in a given time.

Rule. Multiply the number of cubic feet to be discharged by 144 and divide by area of pipe in inches.

Fourth, to find area of pipe when the volume and velocity of water to be discharged are known.

Rule. Multiply volume in cubic feet by 144 and divide by the velocity in feet per minute.

Fifth, one of the first requisites in making correct calculations of the quantity of water discharged from any sized pipe is to obtain the velocity of flow per second. There are several rules for doing this, among which the following appear to be the plainest and most simple:

Rule 1 Multiply the square root of the head in inches by the constant 27.8. For instance, assume the head to be 100 ft. = 1200 in. The square root of 1200 is 35 nearly, then $35\times27.8=973$ in. = 81 ft. per second velocity.

Rule 2. Multiply the square root of the head in feet by the constant 8, as follows: The square of 100 = 10 and $10\times8=80$ ft. velocity per second.

Rule 3. Multiply twice the acceleration of gravity by the head in feet and extract the square root of product. The acceleration of gravity may be considered the constant number 32, neglecting decimals.

$32 \times 2 \times 100 = 6400$. Square root of $6400 = 80$ ft. per second.

In many instances it is more convenient to use the pressure in pounds per square inch as shown by gauge instead of the height or head, and we can then apply Rule 4.

Rule 4. Multiply the square root of the pressure in pounds per square inch by the constant number 12.16 as follows: Pressure due to 100 ft. head = 44 lbs., nearly. Square root of $44 = 6.6$, which multiplied by $12.16 = 80.2$ ft. velocity per second.

Having ascertained the velocity of flow, we may now proceed to calculate the weight of water in pounds per second discharged from any size of pipe, neglecting for the time being the loss in pressure caused by friction from elbows and bends in the pipe and also the peculiar shape assumed by a stream of water flowing through pipes or conduits when there is no resistance except the pressure of the atmosphere and friction caused by long distance transmission.

We will take for our calculation a four-inch pipe from which the water has a free flow under a head of 100 ft., which gives a velocity of 80 ft. per second.

Rule 5. Divide the velocity in feet per second by the constant 2.3, and multiply the quotient by the area of discharge pipe in square inches. $80 \div 2.3 = 34.7$. Now the area of a four-inch pipe is 12.57 sq. in., and $34.7 \times 12.57 = 436$ lbs. discharged per second.

In order to get the matter clearly before us, let us assume that we have a section of four-inch pipe just 80 ft. in length and that it lies in a horizontal position and is filled solidly full of water. It will contain area, 12.57 sq. in. $\times$ length, 960 in. = 12,067.2 cu. in. of water, and as one pound of water occupies a space of

27.7 cu. in., we therefore have 1,2067.2 ÷ 27.7 = 436 lbs. of water, and at a velocity of 80 ft. per second our pipe will be emptied and refilled continuously each second. We have also Rule 6 to find the number of cubic feet discharged per minute when the velocity per minute is known.

Rule 6. Multiply the area of pipe in square inches by the velocity in feet per minute and divide by the constant 144.

Example. Area of 4 in. pipe = 12.57 sq. in. Velocity of flow = 80 ft. per second = 4,800 ft. per minute. Then $\frac{12.57 \times 4,800}{144}$ = 419 cu. ft. per minute = 6.99 cu. ft. per second, which multiplied by 62.3 lbs. (weight of 1 cu. ft.) = 435.4 lbs. per second.

As stated before, no allowance is made by the above rules for friction or other retarding influences, but for ordinary purposes in connection with a steam plant a deduction of 25 per cent. is probably sufficient. Of course if the water is being discharged into an elevated tank or against direct pressure of any kind, the resistance in pounds per square inch or the height in feet must be deducted from the impelling pressure or head. Let us assume, for instance, that our 4 in. pipe is discharging water into a tank at an elevation of 75 ft. above the level of the pump, and that to reach the tank requires 100 ft. of pipe with two 90° ells and one straight-way valve. We wish to discharge 500 gal. per minute into the tank and will therefore require a velocity of about 13 ft. per second, which will necessitate a pressure of a little more than 1 lb. per square inch to be maintained at the pump over and above all resistance. Now the resistance to be overcome in this case will be:

Pressure per square inch due to 75 ft. head,	32.5 lbs.
Friction loss due to length of pipe and velocity,	7.43 "
Friction loss due to two 90° ells,	2.16 "
Friction loss due to straight way valve,	.2 "
Total,	42.29 lbs.

Requiring a pressure of say 43 lbs. per square inch, or about the equivalent of 100 ft. head at the pump.

Again, suppose that in place of the elevated tank we have 1,000 ft. of 8 in. horizontal pipe with a 4 in. delivery at the end farthest from the pump, and three branch pipes each 100 ft. long and 4 in. in diameter with one 90° ell and one straight-way valve, connected at intervals to the 8 in. main, and it is required to discharge in all 1,000 gals. per minute, or at the rate of 250 gals. per minute for each 4 in. delivery. The friction loss for each 100 ft. in length of 8 in. pipe at a velocity of 13 ft. per second is .94 lbs., and for each 100 ft. of 4 in. pipe it is 1.89 lbs. Likewise the friction loss for each 90° ell is 1.08 lbs., and for a straight way valve .2 lbs., at the above velocity. The total resistance therefore to be overcome is as follows:

For 1,000 ft. of 8 in. pipe,	.94 lbs. × 10 = 9.4 lbs.
For 300 ft. of 4 in. pipe,	1.89 lbs. × 3 = 5.67 "
For four 90° ells,	1.08 lbs. × 4 = 4.32 "
For four straight-way valves,	.2 lbs. × 4 = .8 "
Total,	20.19 lbs.

Consequently the pressure required at the pump will be about 22 lbs. per square inch, equal to a head of 50 ft.

Questions

1. What should be the first care of an engineer on entering his boiler room when he goes on watch?

2. What is one of the duties of the fireman before coming off watch?

3. Name the various tools necessary for cleaning fires properly.

4. Describe the operation of cleaning fires.

5. What general rules should be observed in firing?

6. How may the best results be obtained in firing bituminous coal?

7. What will be the result if a sufficient supply of oxygen is not admitted to the furnace?

8. What quantity of air (cubic feet or pounds weight) is required for the complete combustion of one pound of coal?

9. Suppose there is a fusible plug in the boiler and it becomes covered with scale, what will be the result?

10. How long may a boiler be run safely after washing it out?

11. What should be done with a boiler in order to prepare it for washing out?

12. What effect does the too sudden cooling off or firing up of a boiler have upon the seams?

13. What other bad result takes place within the boiler when it is emptied of water while hot?

14. What should be done with tubes that have become badly scaled?

15. How fast should the feed water be supplied?

16. What should be done in case the supply of feed water be cut off suddenly?

17. What is the proper method of connecting a recently fired up boiler to the main header?

18. What are some of the dangerous results of foaming?

19. What can be done to prevent or at least to modify foaming in boilers?

20. Which are the most reliable pop valves or lever safety valves?

21. What is the rule regulating the area of lever safety valves?

22. What two factors must first be known before correct calculations can be made as to the weight and position of the ball on a lever safety valve?

23. How may the effective weight of the lever and that of the valve and stem be found?

24. When the area in square inches of the valve, the weight of the valve and stem, the effective weight of the lever, the weight of the ball and its distance from the fulcrum are known, how is the pressure at which the valve will blow off ascertained?

25. When the pressure at which the valve should blow off is known, together with the weights of all the parts, how may the distance the ball should be from the fulcrum be ascertained?

26. When the pressure is known, together with the distance of the ball from the fulcrum, how is the weight of the ball found?

27. What should be done with a safety valve in order to keep it in good working condition?

28. Describe the process of setting the steam valves of a duplex pump.

29. How may a duplex pump be operated in case one of the water pistons becomes disabled?

30. How is the velocity of flow or piston speed per minute of a pump ascertained?

31. The piston speed being known, how is the velocity of flow in the discharge pipe found?

32. When it is required to discharge a certain quantity of water from a given size of pipe in a given time, how may the velocity of flow in feet per minute be found?

33. When the volume of water to be discharged and the velocity of flow are known, how is the area of the pipe obtained?

34. What is meant by "acceleration of gravity," and what constant number represents it in connection with hydraulics?

35. What per cent. of allowance is ordinarily made for friction in water pipes?

CHAPTER IV

COMBUSTION—WATER—STEAM

Combustion—Composition of air—Carbon—The principal constituent of fuels—Hydrogen, its nature and heating value—Table, giving analysis of various coals—Process of combustion described—Quantity of air required—Furnace temperature—How to utilize the heat in the escaping gases—Heat, what it is and how produced—Joule's researches—The heat unit—Specific heat—Sensible heat and latent heat—Experiments of Professor Black—Total heat of evaporation—Water, its composition, nature, etc.—Steam, its expansive nature, temperature, etc.—Saturated steam, etc.—Total heat of steam—Density of steam.

Combustion. The subject of the combustion of fuels being one in which every engineer is vitally interested, it is proper that its leading features and principles be discussed. One of the main factors in the combustion of coal is the proper supply of air. Air is composed of two gases, oxygen and nitrogen, in the proportion, by volume, of 21 per cent. of oxygen and 79 per cent. of nitrogen, or by weight, 23 per cent. of oxygen and 77 per cent. of nitrogen.

The composition of pure dry air, as given by Kent in *Steam Boiler Economy*, is as follows:

By volume, 20.91 parts O. and 79.09 parts N.

By weight, 23.15 parts O. and 76.85 parts N.

Air is a mixture and not a chemical combination of these two elements. The principal constituent of coal and most other fuels, whether solid, liquid or gaseous, is carbon. Hydrogen is a light combustible gas and combined either with carbon or with carbon and

oxygen, in various proportions, is also a valuable constituent of fuels, notably of bituminous coal. The heating value of one pound of pure carbon is rated at 14,500 heat units, while one pound of hydrogen gas contains 62,000 heat units.

Analysis of coal shows that it contains moisture, fixed carbon, volatile matter, ash and sulphur in various proportions according to the quality of the coal. The following table deduced from a few of the many valuable tables of analysis of the coals of the United States, as given by Mr. Kent, will show the composition of the principal bituminous coals in use in this country for steam purposes. Two samples are selected from each of the great coal producing states, with the exception of Illinois, from which four were taken.

TABLE 2

State	Kind of Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Pennsylvania	Youghiogheny	1.03	36.49	59.05	2.61	0.81
"	Connellsville	1.26	30.10	59.61	8.23	0.78
West Virginia	Quinimont	0.76	18.65	79.26	1.11	0.23
"	Fire Creek	0.61	22.34	75.02	1.47	0.56
E. Kentucky	Peach Orchard	4.60	35.70	53.28	6 42	1.08
"	Pike County	1.80	26.80	67.60	3.80	0.97
Alabama	Cahaba	1.66	33.28	63.04	2.02	0.53
"	Pratt Co.'s	1.47	32.29	59 50	6.73	1.22
Ohio	Hocking Valley	6.59	35.77	49.64	8.00	1.59
"	Muskingum "	3.47	37.88	53.30	5.35	2.24
Indiana	Block	8.50	31.00	57.50	3.00	
"	"	2.50	44 75	51.25	1.50	
W. Kentucky	Nolin River	4.70	33.24	54.94	11.70	2.54
"	Ohio County	3.70	30.70	45.00	3.16	1.24
Illinois	Big Muddy	6.40	30.60	54.60	8.30	1.50
"	Wilmington	15.50	32.80	39.90	11.80	
"	" screenings	14.00	28.00	34.20	23.80	
"	Duquoin	8.90	23.50	60.60	7.00	

The process of combustion consists in the union of the carbon and hydrogen of the fuel with the oxygen

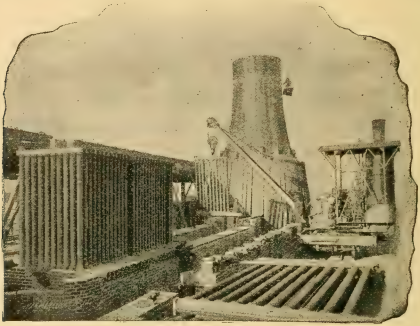
of the air. Each atom of carbon combines with two atoms of oxygen, and the energetic vibration set up by their combination is heat. Bituminous coal contains a large percentage of volatile matter which is released and flashes into flame when the coal is thrown into the furnace, and unless air is supplied in large amounts at this stage of the combustion there will be an excess of smoke and consequent loss of carbon. On the other hand there is a loss in admitting too much air because the surplus is heated to the temperature of the furnace without aiding the combustion and will carry off to the chimney just as many heat units as were required to raise it from the temperature at which it entered the furnace to that at which it enters the uptake. It will therefore be seen that a great advantage will be gained by first allowing the air that is needed above the fire to pass over or through heated bridge walls or side walls. Some kinds of coal need more air for their combustion than do others, and good judgment and close observation are needed on the part of the fireman to properly regulate the supply.

Some boilers will make steam more economically by partly closing the ash-pit doors, while others require the same doors to be kept wide open. The quantity of air required for the combustion of one pound of coal is, by volume, about 150 cu. ft.; by weight, about 12 lbs.

The temperature of the furnace is usually about 2500°, in some cases reaching as high as 3000°. The temperature of the escaping gases should not be much above nor below 400° F. for bituminous coal. The waste heat in the escaping gases can be utilized to great advantage by passing them through what are called economizers before they escape into the chim-

ney. These economizers consist of coils or stacks of cast iron pipe placed within the flue or breeching leading from the boilers to the chimney and are enveloped in the hot gases, while the feed water is passed through the pipes on its way to the boilers, the result being that considerable heat is thus imparted to the feed water that would otherwise go to waste.

In order to attain the highest economy in the burning of coal in boiler furnaces two factors are indispen-



GREEN'S FUEL ECONOMIZER UNDER CONSTRUCTION.

sable, viz., a constant high furnace temperature and quick combustion, and these factors can only be secured by supplying the fresh coal constantly just as fast as it is burned, and also by preventing as much as possible the admission of cold air to the furnace. This is why the automatic or mechanical stoker, if it be of the proper design, is more economical and causes less smoke than hand firing. The fireman when he puts in a fire is prone to shovel in a good supply all at once, and this has the tendency to

greatly reduce the temperature of the furnace, while at the same time it retards combustion. On the other hand the mechanical stoker supplies the coal continuously only as fast as it is required and no faster, and the furnace doors do not need to be opened at all, by which a large volume of cold air is prevented from entering the furnace and reducing the temperature. The author does not wish to be understood as recommending the adoption and use of mechanical stokers to replace hand firing, but he draws this contrast between the two methods of firing in order that it may be of some benefit to the thousands of honest toilers who earn a livelihood by shoveling coal into boiler furnaces.

The problem of the economical use of coal and the abatement of the smoke nuisance, especially in our large cities, has of late years become so serious that it is to the interest of every engineer, and especially every fireman, to use the utmost diligence, care and good judgment in the use of coal, and to emulate as much as possible the methods of the mechanical stoker.

Heat. All matter, whether solid, liquid or gaseous, consists of molecules or atoms, which are in a state of continual vibration, and the result of this vibration is heat. The intensity of the heat evolved depends upon the degree of agitation to which the molecules are subject.

Until as late as the beginning of the nineteenth century two rival theories in regard to the nature of heat had been advocated by scientists. The older of these theories was that heat was a material substance, a subtle elastic fluid termed caloric, and that this fluid penetrated matter something like water penetrates a

sponge. But this theory was shown to be false by the wonderful researches and experiments of Count Rumford at Munich, Bavaria, in 1798.

By means of the friction between two heavy metallic bodies placed in a wooden trough filled with water, one of the pieces of metal being rotated by machinery driven by horses, Count Rumford succeeded in raising the temperature of the water in two and one-half hours from its original temperature of 60° to 212° F., the boiling point, thus demonstrating that heat is not a material substance, but that it is due to vibration or motion, an internal commotion among the molecules of matter. This theory, known as the Kinetic theory of heat, has since been generally accepted, although it was nearly fifty years after Rumford advocated it in a paper read before the Royal Society of Great Britain in 1798, before scientists generally became converted to this idea of the nature of heat and the science of Thermo Dynamics placed on a firm basis.

During the period from 1840 to 1849 Dr. Joule made a series of experiments which not only confirmed the truth of Count Rumford's theory that heat was not a material substance but a form of energy which may be applied to or taken away from bodies, but Joule's experiments also established a method of estimating in mechanical units or foot pounds the amount of that energy. This latter was a most important discovery because by means of it the exact relation between heat and work can be accurately measured.

The first law of thermo dynamics is this: Heat and mechanical energy or work are mutually convertible. That is, a certain amount of work will produce a certain amount of heat, and the heat thus produced is capable of producing by its disappearance a fixed

amount of mechanical energy if rightly applied. The mechanical energy in the form of heat which, through the medium of the steam engine, has revolutionized the world, was first stored up by the sun's heat millions of years ago in the coal which in turn, by

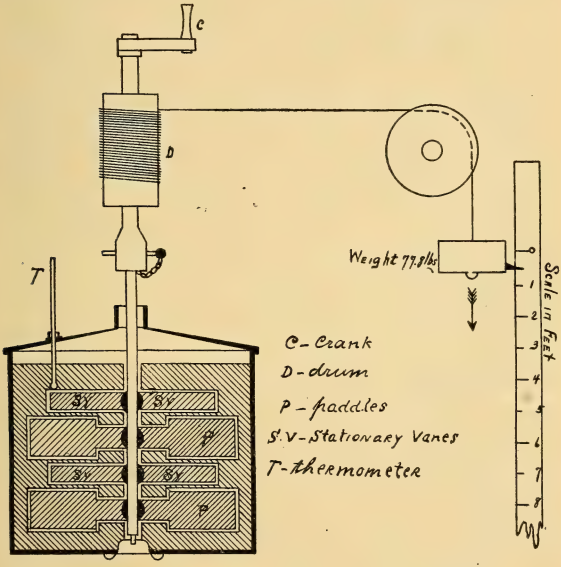


FIGURE 11

combustion, is made to release it for purposes of mechanical work.

The general principles of Dr. Joule's device for measuring the amount of work in heat are illustrated in Fig. 11. It consisted of a small copper cylinder

containing a known quantity of water at a known temperature. Inside the cylinder and extending through the top was a vertical shaft to which were fixed paddles for stirring the water. Stationary vanes were also placed inside the cylinder. Motion was imparted to the shaft through the medium of a cord or small rope coiled around a drum near the top of the shaft and running over a grooved pulley or sheave. To the free end of the cord a known weight was attached. This weight was allowed to fall through a certain distance, and in falling it turned the shaft with its paddles, which in turn agitated the water, thus producing a certain amount of heat. To illustrate, suppose the weight to be 77.8 lbs., and that by means of the crank at the top end of the shaft it has been raised to the zero mark at the top of the scale. (See Fig. 11.) One pound of water at 39.1° F. is poured into the copper cylinder, which is then closed and the weight released. At the moment the weight passes the 10 ft. mark on the scale, the thermometer attached to the cylinder will indicate that the temperature of the water has been raised one degree. Then multiplying the number of pounds in the weight by the distance in feet through which it fell will give the number of foot pounds of work done. Thus, 77.8 lbs. × 10 ft. = 778 foot pounds.

The heat unit or British thermal unit (B. T. U.) is the quantity of heat required to raise the temperature of one pound of water one degree, or from 39° to 40° F., and the amount of mechanical work required to produce a unit of heat is 778 foot pounds. Therefore the mechanical equivalent of heat is the energy required to raise 778 lbs. one foot high, or 77.8 lbs. 10 ft. high, or 1 lb. 778 feet high. Or again, suppose

a one-pound weight falls through a space of 778 ft. or a weight of 778 lbs. falls one foot, enough mechanical energy would thus be developed to raise a pound of water one degree in temperature, provided all the energy so developed could be utilized in churning or stirring the water, as in Joule's machine. Hence the mechanical equivalent of heat is 778 foot pounds.

Specific Heat. The specific heat of any substance is the ratio of the quantity of heat required to raise a given weight of that substance one degree in temperature to the quantity of heat required to raise an equal weight of water one degree in temperature when the water is at its maximum density, 39.1° F. To illustrate, take the specific heat of lead, for instance, which is .031, while the specific heat of water is 1. That means that it would require 31 times as much heat to raise one pound of water one degree in temperature as it would to raise the temperature of a pound of lead one degree.

The following table gives the specific heat of different substances in which engineers are most generally interested.

TABLE 3.

Water at 39.1° F.	1.000
Ice at 32° F.	.504
Steam at 212° F.	.480
Mercury	.033
Cast iron	.130
Wrought iron	.113
Soft steel	.116
Copper	.095
Lead	.031
Coal	.240
Air	.238
Hydrogen	3.404
Oxygen	.218
Nitrogen	.244

Sensible Heat and Latent Heat. The plainest and most simple definition of these two terms is that given

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by Sir Wm. Thomson. He says: "Heat given to a body and warming it is sensible heat. Heat given to a body and not warming it is latent heat." Sensible heat in a substance is the heat that can be measured in degrees of a thermometer, while latent heat is the heat in any substance that is not shown by the thermometer.

To illustrate this more fully a brief reference to some experiments made by Professor Black in 1762 will no doubt make the matter plain. It will be remembered that at that early date comparatively little was known of the true nature of heat, hence Professor Black's investigations and discoveries along this line appear all the more wonderful. He procured equal weights of ice at 32° F. and water at the same temperature, that is, just at the freezing point, and placing them in separate glass vessels suspended the vessels in a room in which the uniform temperature was 47° F. He noticed that in one-half hour the water had increased 7° F. in temperature, but that twenty half hours elapsed before all of the ice was melted. Therefore he reasoned that twenty times more heat had entered the ice than had entered the water, because at the end of the twenty half hours when the ice was all melted the water in both vessels was of the same temperature. The water having absorbed 7° of heat during the first half hour must have continued to absorb heat at the same rate during the whole of the twenty half hours, although the thermometer did not indicate it. From this he calculated that $7° \times 20 = 140°$ of heat had become latent or hidden in the water.

In another experiment Professor Black placed a lump of melting ice, which he estimated to be at a

temperature of 33° F. on the surface, in a vessel containing the same weight of water at 176° F., and he observed that when the whole of the ice had been melted the temperature of the water was 33° F., thus proving that 143° of heat (176° − 33°) had been absorbed in melting the ice and was at that moment latent in the water By these two experiments Professor Black established the theory of the latent heat of water, and his estimate was very near the truth because the results obtained since that time by the greatest experimenters show that the latent heat of water is 142 heat units, or B. T. U.

Black's experiment for ascertaining the latent heat in steam at atmospheric pressure was made in the following simple manner: He placed a flat, open tin dish on a hot plate over a fire and into the dish he put a small quantity of water at 50° F. In four minutes the water began to boil, and in twenty minutes more it had all evaporated. In the first four minutes the temperature had increased 212° − 50° = 162°, and the temperature remained at 212° throughout the twenty minutes that it required to evaporate all the water, despite the fact that the water had been receiving heat during this period at the same rate as during the first four minutes. He therefore reasoned that in the twenty minutes the water had absorbed five times as much heat as it had in the four minutes, or 162° × 5 = 810°, without any sensible rise in temperature. Therefore the 810° became latent in the steam. Owing to the crude nature of the experiment Professor Black's estimate of the number of degrees of latent heat in steam was incorrect, as it has been proven by many famous experimenters since then that the latent heat of steam at atmospheric pressure is 965.7 B. T. U.

It will thus be perceived that what is meant by the term latent heat is that quantity of heat which becomes hidden or latent when the state of a body is changed from a solid to a liquid, as in the case of melting ice, or from a liquid to a gaseous state, as with water evaporated into steam. But the heat so disappearing has not been lost, on the contrary it has, while becoming latent, been doing an immense amount of work, as can easily be ascertained by means of a few simple figures. It has been seen that a heat unit is the quantity of heat required to raise one pound of water one degree in temperature and also that the mechanical equivalent of heat, or, in other words, the mechanical energy stored in one heat unit is equal to 778 foot pounds of work.

A horse power equals 33,000 ft. lbs. of energy in one minute of time, and a heat unit = 778 ÷ 33,000 = .0236, or about $\frac{1}{43}$ of a horse power. The work done by the heat which becomes latent in converting one pound of ice at 32° F. into water at the same temperature = 142 heat units × 778 ft. lbs. = 110,476 ft. lbs., which divided by 33,000 equals 3.34 horse power. Again, by the evaporation of one pound of water from 32° F. into steam at atmospheric pressure, 965.7 units of heat become latent in the steam and the work done = 965.7 × 778 = 751,314 ft. lbs. = 22.7 horse power. It will thus be seen what tremendous energy lies stored in one pound of coal, which contains from 12,000 to 14,500 heat units, provided all the heat could be utilized in an engine.

Total Heat of Evaporation. In order to raise the temperature of one pound of water from the freezing point, 32° F., to the boiling point, 212° F., there must be added to the temperature of the water 212° − 32° =

180°. This represents the sensible heat Then to make the water boil at atmospheric pressure, or, in other words, to evaporate it, there must still be added 965.7 B. T. U., thus 180 + 965.7 = 1,145.7, or in round numbers 1,146 heat units. This represents what is termed the total heat of evaporation at atmospheric pressure and is the sum of the sensible and latent heat in steam at that pressure. But if a thermometer were held in steam evaporating into the open air, as, for instance, in front of the spout of a tea-kettle, it would indicate but 212° F.

When steam is generated at a higher pressure than 212°, the sensible heat increases and the latent heat decreases slowly, while at the same time the total heat of evaporation slowly increases as the pressure increases, but not in the same ratio. As, for instance, the total heat in steam at atmospheric pressure is 1,146 B. T. U., while the total heat in steam at 100 lbs. gauge pressure is 1,185 B. T. U., and the sensible temperature of steam at atmospheric pressure is 212°, while at 100 lbs. gauge pressure the temperature is 338 and the latent heat is 876 B. T. U. See table.

Water. The elements that enter into the composition of pure water are the two gases, hydrogen and oxygen, in the following proportions:

By volume, hydrogen 2, oxygen 1.
By weight, " 11.1, " 88.9.

Perfectly pure water is not attainable, neither is it desirable nor necessary to the welfare of the human race, because the presence of certain proportions of air and ammonia add greatly to its value as an agent for manufacturing purposes and for generating steam. The nearest approach to pure water is rain water, but even this contains 2.5 volumes of air to each 100 vol-

umes of water. Pure distilled water, such for instance as the return water from steam heating systems, is not desirable for use alone in a boiler as it will cause corrosion and pitting of the sheets, but if it is mixed with other water before going into the boiler its use is highly beneficial, as it will prevent to a certain degree the formation of scale and incrustation. Nearly all water used for the generation of steam in boilers contains more or less scale-forming matter, such as the carbonates of lime and magnesia, the sulphates of lime and magnesia, oxide of iron, silica and organic matter, which latter tends to cause foaming in boilers.

The carbonates of lime and magnesia are the chief causes of incrustation. The sulphate of lime forms a hard crystalline scale which is extremely difficult to remove when once formed on the sheets and tubes of boilers. Of late years the intelligent application of chemistry to the analyzing of feed waters has been of great benefit to engineers and steam users, in that it has enabled them to properly treat the water with solvents either before it is pumped into the boiler, or by the introduction into the boiler of certain scale preventing compounds made especially for treating the particular kind of water used. Where it is necessary to treat water in this manner great care and watchfulness should be exercised by the engineer in the selection and use of a boiler compound.

From ten to forty grains of mineral matter per gallon are held in solution by the waters of the different rivers, streams and lakes; well and mine water contain still more.

Water contracts and becomes denser in cooling until it reaches a temperature of 39.1° F., its point of greatest density. Below this temperature it expands and

at 32° F. it becomes solid or freezes, and in the act of freezing it expands considerably, as every engineer who has had to deal with frozen water pipes can testify.

Water is 815 times heavier than atmospheric air. The weight of a cubic foot of water at 39.1° is approximately 62.5 lbs., although authorities differ on this matter, some of them placing it at 62.379 lbs., and others at 62.425 lbs. per cubic foot. As its temperature increases its weight per cubic foot decreases until at 212° F. one cubic foot weighs 59.76 lbs.

The table which follows is compiled from various sources and gives the weight of a cubic foot of water at different temperatures.

TABLE 4

Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot
32° F.	62.42 lbs.	132° F.	61.52 lbs.	230° F.	59.37 lbs.
42°	62.42	142°	61.34	240°	59.10
52°	62.40	152°	61.14	250°	58.85
62°	62.36	162°	60.94	260°	58.52
72°	62.30	172°	60.73	270°	58.21
82°	62.21	182°	60.50	300°	57.26
92°	62.11	192°	60.27	330°	56.24
102°	62.00	202°	60.02	360°	55.16
112°	61.86	212°	59.76	390°	54.03
122°	61.70	220°	59.64	420°	52.86

The boiling point of water varies according to the pressure to which it is subject. In the open air at sea level the boiling point is 212° F. When confined in a boiler under steam pressure the boiling point of water depends upon the pressure and temperature of the steam, as, for instance, at 100 lbs. gauge pressure the temperature of the steam is 338° F., to which temper-

ature the water must be raised before its molecules will separate and be converted into steam. In the absence of any pressure, as in a perfect vacuum, water boils at 32° F. temperature. In a vacuum of 28 in., corresponding to an absolute pressure of .943 lbs., water will boil at 100°, and in a vacuum of 26 in., at which the absolute pressure is 2 lbs., the boiling point of water is 127° F. On the tops of high mountains in a rarefied atmosphere water will boil at a much lower temperature than at sea level, for instance at an altitude of 15,000 ft. above sea level water boils at 184° F.

Steam. Having discussed to some extent the physical properties of water, it is now in order to devote some time to the study of the nature of steam, which is simply water in its gaseous form made so by the application of heat.

As has been stated in another portion of this book, matter consists of molecules or atoms inconceivably small in size, yet each having an individuality, and in the case of solids or liquids, each having a mutual cohesion or attraction for the other, and all being in a state of continual vibration more or less violent according to the temperature of the body.

The law of gravitation which holds the universe together, also exerts its wonderful influence on these atoms and causes them to hold together with more or less tenacity according to the nature of the substance. Thus it is much more difficult to chip off pieces of iron or granite than it is of wood. But in the case of water and other liquids the atoms, while they adhere to each other to a certain extent, still they are not so hard to separate, in fact, tney are to some extent repulsive to each other, and unless confined within certain bounds

the atoms will gradually scatter and spread out, and finally either be evaporated or sink out of sight in the earth's surface. Heat applied to any substance tends to accelerate the vibrations of the molecules, and if enough heat is applied it will reduce the hardest substances to a liquid or gaseous state.

The process of the generation of steam from water is simply an increase of the natural vibrations of the molecules of the water, caused by the application of heat until they lose all attraction for each other and become instead entirely repulsive, and unless confined will fly off into space. But being confined they continually strike against the sides of the containing vessel, thus causing the pressure which steam or any other gas exerts when under confinement.

Of course steam, like other gases, when under pressure is invisible, but the laws governing its action are well known. These laws, especially those relating to the expansion of steam, will be more fully discussed in the chapters on the Indicator. The temperature of steam in contact with the water from which it is generated, as for instance in the ordinary steam boiler, depends upon the pressure under which it is generated. Thus at atmospheric pressure its temperature is 212° F. If the vessel is closed and the pressure increased the temperature of the steam and also that of the water rises.

Saturated Steam. When steam is taken directly from the boiler to the engine without being superheated, it is termed saturated steam. This does not necessarily imply that it is wet and mixed with spray and moisture.

Superheated Steam. When steam is conducted into or through a vessel or coils of pipe separate from the

boiler in which it was generated and is there heated to a higher temperature than that due to its pressure, it is said to be superheated.

Dry Steam. When steam contains no moisture it is said to be dry. Dry steam may be either saturated or superheated.

Wet Steam. When steam contains mist or spray intermingled it is termed wet steam, although it may have the same temperature as dry saturated steam of the same pressure.

During the further consideration of steam in this book, saturated steam will be mainly under discussion for the reason that this is the normal condition of steam as used most generally in steam engines.

Total Heat of Steam. The total heat in steam includes the heat required to raise the temperature of the water from 32° F. to the temperature of the steam plus the heat required to evaporate the water at that temperature. This latter heat becomes latent in the steam, and is therefore called the latent heat of steam.

The work done by the heat acting within the mass of water and causing the molecules to rise to the surface is termed by scientists internal work, and the work done in compressing the steam already formed in the boiler or in pushing it against the superincumbent atmosphere, if the vessel be open, is termed external work. There are, therefore, in reality three elements to be taken into consideration in estimating the total heat of steam, but as the heat expended in doing external work is done within the mass itself it may, for practical purposes, be included in the general term latent heat of steam.

Density of Steam. The expression density of steam means the actual weight in pounds or fractions of a

pound avoirdupois of a given volume of steam, as one cubic foot. This is a very important point for young engineers especially to remember, so as not to get the two terms, pounds pressure and pounds weight, mixed, as some are prone to do.

Volume of Steam. By this term is meant the volume as expressed by the number of cubic feet in one pound weight of steam.

Relative Volume of Steam. This expression has reference to the number of volumes of steam produced from one volume of water. Thus the steam produced by the evaporation of one cubic foot of water from 39° F. into steam at atmospheric pressure will occupy a space of 1646 cu. ft., but, as the steam is compressed and the pressure allowed to rise, the relative volume of the steam becomes smaller, as for instance at 100 lbs. gauge pressure the steam produced from one cubic foot of water will occupy but 237.6 cu. ft., and if the same steam was compressed to 1,000 lbs. absolute or 985.3 lbs. gauge pressure it would then occupy only 30 cu. ft.

The condition of steam as regards its dryness may be approximately estimated by observing its appearance as it issues from a pet cock or other small opening into the atmosphere. Dry or nearly dry steam containing about 1 per cent. of moisture will be transparent close to the orifice through which it issues, and even if it is of a grayish white color it may be estimated to contain not over 2 per cent. of moisture.

Steam in its relation to the engine should be considered in the character of a vehicle for transferring the energy, created by the heat, from the boiler to the engine. For this reason all steam drums, headers and pipes should be thoroughly insulated in order to

prevent, as much as possible, the loss of heat or energy by radiation.

Table 5, showing the properties of saturated steam, is compiled mainly from Kent's *Steam Boiler Economy*. The decimals have not been carried out in the columns headed Relative Volume and Weight of 1 cu. ft. of steam, as their absence will affect the results very little.

TABLE 5

PROPERTIES OF SATURATED STEAM

Vacuum Inches of Mercury	Absolute Pressure Lbs. per Sq. Inch	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
29.74	.089	32.	0.	1091.7	1091.7	208,080	3333.3	.0003
29.67	.122	40.	8.	1094.1	1086.1	154,330	2472.2	.0004
29.56	.176	50.	18.	1097.2	1079.2	107,630	1724.1	.0006
29.40	.254	60.	28.01	1100.2	1072.2	76,370	1223.4	.0008
29.19	.359	70.	38.02	1103.3	1065.3	54,660	875.61	.0011
28.90	.502	80.	48.04	1106.3	1058.3	39,690	635.80	.0016
28.51	.692	90.	58.06	1109.4	1051.3	29,290	469.20	.0021
28 00	.943	100.	68.08	1112.4	1044.4	21,830	349.70	.0028
27.88	1.	102.1	70.09	1113.1	1043.0	20,623	334.23	.0030
25 85	2.	126.3	94.44	1120.5	1026.0	10,730	173.23	.0058
23.83	3.	141.6	109.9	1125.1	1015.3	7,325	118.00	.0085
21.78	4.	153.1	121.4	1128 6	1007.2	5,588	89.80	.0111
19.74	5.	162.3	130.7	1131.4	1000.7	4,530	72.50	.0137
17.70	6.	170.1	138.6	1133.8	995.2	3,816	61.10	.0163
15.67	7.	176.9	145.4	1135.9	990.5	3,302	53.00	.0189
13.63	8.	182.9	151.5	1137.7	986.2	2,912	46.60	.0214
11.60	9.	188.3	156.9	1139.4	982.4	2,607	41.82	.0239
9.56	10.	193.2	161.9	1140.9	979.0	2,361	37.80	.0264
7.52	11.	197.8	166.5	1142 3	975.8	2,159	34.61	.0289
5.49	12.	202.0	170.7	1143.5	972.8	1,990	31.90	.0314
3.45	13.	205.9	174.7	1144.7	970.0	1,846	29.60	.0338
1.41	14.	209.6	178.4	1145.9	967.4	1,721	27.50	.0363
0.00	14.7	212.0	180.9	1146.6	965.7	1,646	26.36	.0379

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
0.3	15	213.3	181.9	1146.9	965.0	1,614	25.90	.0387
1.3	16	216.3	185.3	1147.9	962.7	1,519	24.33	.0411
2.3	17	219.4	188.4	1148.9	960.5	1,434	23.00	.0435
3.3	18	222.4	191.4	1149.8	958.3	1,359	21.80	.0459
4.3	19	225.2	194.3	1150.6	956.3	1,292	20.70	.0483
5.3	20	227.9	197.0	1151.5	954.4	1,231	19.72	.0507
6.3	21	230.5	199.7	1152.2	952.6	1,176	18.84	.0531
7.3	22	233.0	202.2	1153.0	950.8	1,126	18.03	.0555
8.3	23	235.4	204.7	1153.7	949.1	1,080	17.30	.0578
9.3	24	237.8	207.0	1154.5	947.4	1,038	16.62	.0602
10.3	25	240.0	209.3	1155.1	945.8	998	16.00	.0625
11.3	26	242.2	211.5	1155.8	944.3	962	15.42	.0649
12.3	27	244.3	213.7	1156.4	942.8	929	14.90	.0672
13.3	28	246.3	215.7	1157.1	941.3	898	14.40	.0696
14.3	29	248.3	217.8	1157.7	939.9	869	13.91	.0719
15.3	30	250.2	219.7	1158.3	938.9	841	13.50	.0742
16.3	31	252.1	221.6	1158.8	937.2	816	13.07	.0765
17.3	32	254.0	223.5	1159.4	935.9	792	12.68	.0788
18.3	33	255.7	225.3	1159.9	934.6	769	12.32	.0812
19.3	34	257.5	227.1	1160.5	933.4	748	12.00	.0835
20.3	35	259.2	228.8	1161.0	932.2	728	11.66	.0858
21.3	36	260.8	230.5	1161.5	931.0	709	11.36	.0880
22.3	37	262.5	232.1	1162.0	929.8	691	11.07	.0903
23.3	38	264.0	233.8	1162.5	928.7	674	10.80	.0926
24.3	39	265.6	235.4	1162.9	927.6	658	10.53	.0949
25.3	40	267.1	236.9	1163.4	926.5	642	10.28	.0972
26.3	41	268.6	238.5	1163.9	925.4	627	10.05	.0995
27.3	42	270.1	240.0	1164.3	924.4	613	9.83	.1018
28.3	43	271.5	241.4	1164.7	923.3	600	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587	9.41	.1063
30.3	45	274.3	244.3	1165.6	921.3	575	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563	9.02	.1108
32.3	47	277.0	247.0	1166.4	919.4	552	8.84	.1131
33.3	48	278.3	248.4	1166.8	918.5	541	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	531	8.50	.1176
35.3	50	280.9	251.0	1167.6	916.6	520	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	511	8.19	.1221
37.3	52	283.3	253.5	1168.4	914.9	502	8.04	.1243

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam. Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
38.3	53	284.5	254.7	1168.7	914.0	492	7.90	.1266
39.3	54	285.7	256.0	1163.1	913.1	484	7.76	.1288
40.3	55	286.9	257.2	1169 4	912.3	476	7.63	.1311
41.3	56	288.1	258.3	1169.8	911.5	468	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460	7.38	.1355
43 3	58	290.3	260.7	1170.5	909.8	453	7.26	.1377
44.3	59	291.4	261.8	1170.8	909.0	446	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	439	7.03	.1422
46.3	61	293.6	264.0	1171.5	907.5	432	6.92	.1444
47.3	62	294.7	265.1	1171.8	906.7	425	6.82	.1466
48 3	63	295.7	266.2	1172.1	905.9	419	6.72	.1488
49.3	64	296.8	267.2	1172.4	905.2	413	6.62	.1511
50.3	65	297.8	268.3	1172.8	904.5	407	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	401	6 43	.1555
52.3	67	299.8	270.4	1173.4	903.0	395	6.34	.1577
53 3	68	300.8	271 4	1173.7	902.3	390	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384	6.17	.1621
55.3	70	302.7	273.4	1174.3	900.9	379	6.09	.1643
56.3	71	303.7	274.4	1174.6	900.2	374	6.01	.1665
57.3	72	304.6	275.3	1174.8	899.5	369	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	365	5.85	.1709
59.3	74	306.5	277.2	1175.4	898.2	360	5 78	.1731
60.3	75	307.4	278.2	1175.7	897.5	356	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351	5.63	.1775
62.3	77	309.2	280.0	1176.2	896.2	347	5.57	.1797
63.3	78	310.1	280.9	1176.5	895.6	343	5.50	.1819
64.3	79	310.9	281.8	1176.8	895.0	339	5.43	.1840
65 3	80	311.8	282 7	1177.0	894.3	334	5.37	.1862
66.3	81	312.7	283.6	1177.3	893.7	331	5.31	.1884
67.3	82	313.5	284.5	1177.6	893.1	327	5.25	.1906
68.3	83	314.4	285.3	1177.8	892.5	323	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	320	5.13	.1950
70 3	85	316.0	287.0	1178.3	891.3	316	5.07	.1971
71.3	86	316.8	287.9	1178.6	890 7	313	5.02	.1993
72.3	87	317.7	288.7	1178.8	890.1	309	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	306	4.91	.2036
74.3	89	319.3	290 4	1179.3	888.9	303	4.86	.2058
75.3	90	320.0	291.2	1179.6	888.4	299	4.81	.2080

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
76.3	91	320.8	292.0	1179.8	887.8	296	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293	4.71	.2123
78.3	93	322.4	293.6	1180.3	886.7	290	4.66	.2145
79.3	94	323.1	294.4	1180.5	886 1	287	4.62	.2166
80.3	95	323.9	295.1	1180 7	885.6	285	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	282	4.53	.2210
82.3	97	325.4	296.7	1181.2	884.5	279	4.48	.2231
83.3	98	326.1	297.4	1181.4	884.0	276	4.44	.2253
84.3	99	326.8	298.2	1181.6	883.4	274	4.40	.2274
85.3	100	327.6	298.9	1181.8	882.9	271	4.36	.2296
86.3	101	328.3	299.7	1182.1	882 4	268	4.32	.2317
87.3	102	329.0	300.4	1182.3	881.9	266	4.28	.2339
88.3	103	329.7	301.1	1182.5	881.4	264	4.24	.2360
89.3	104	330.4	301.9	1182 7	880.8	261	4.20	.2382
90.3	105	331.1	302.6	1182.9	880.3	259	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	257	4.12	.2425
92.3	107	332.5	304.0	1183.4	879.3	254	4.09	.2446
93.3	108	333.2	304.7	1183.6	878.8	252	4.05	.2467
94.3	109	333.9	305.4	1183.8	878.3	250	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	248	3.98	.2510
96.3	111	335.2	306.8	1184.2	877.4	246	3.95	.2531
97.3	112	335.9	307.5	1184.4	876.9	244	3.92	.2553
98.3	113	336.5	308.2	1184.6	876.4	242	3.88	.2574
99.3	114	337.2	308.8	1184.8	875.9	240	3.85	.2596
100.3	115	337.8	309.5	1185.0	875.5	238	3.82	.2617
101.3	116	338.5	310.2	1185.2	875.0	236	3.79	.2638
102.3	117	339.1	310.8	1185.4	874.5	234	3.76	.2660
103.3	118	339.7	311.5	1185.6	874.1	232	3.73	.2681
104.3	119	340.4	312.1	1185.8	873.6	230	3.70	.2703
105.3	120	341.0	312 8	1185.9	873.2	228	3.67	.2764
106.3	121	341.6	313.4	1186.1	872.7	227	3.64	.2745
107.3	122	342.2	314.1	1186.3	872.3	225	3.62	.2766
108.3	123	342.9	314.7	1186.5	871.8	223	3.59	.2788
109.3	124	343.5	315.3	1186.7	871.4	221	3.56	.2809
110.3	125	344.1	316.0	1186.9	870.9	220	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218	3.51	2851
112.3	127	345.3	317.2	1187.3	870.0	216	3.48	.2872
113.3	128	345.9	317.8	1187.4	869.6	215	3.46	.2894

TABLE 5—*Continued*

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat Above 32° F.		Latent Heat $H-h$ Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
114.3	129	346.5	318.4	1187.6	869.2	213	3.43	.2915
115.3	130	347.1	319.1	1187.8	868.7	212	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210	3.38	.2957
117.3	132	348.2	320.3	1188.2	867.9	209	3.36	.2978
118.3	133	348.8	320.8	1188.3	867.5	207	3.33	.3000
119.3	134	349.4	321.5	1188.5	867.0	206	3.31	.3021
120.3	135	350.0	322.1	1188.7	866.6	204	3.29	.3042
121.3	136	350.5	322.6	1188.9	866.2	203	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201	3.24	.3084
123.3	138	351.8	323.8	1189.2	865.4	200	3.22	.3105
124.3	139	352.2	324.4	1189.4	865.0	199	3.20	.3126
125.3	140	352.8	325.0	1189.5	864.6	197	3.18	.3147
126.3	141	353.3	325.5	1189.7	864.2	196	3.16	.3169
127.3	142	353.9	326.1	1189.9	863.8	195	3.14	.3190
128.3	143	354.4	326.7	1190.0	863.4	193	3.11	.3211
129.3	144	355.0	327.2	1190.2	863.0	192	3.09	.3232
130.3	145	355.5	327.8	1190.4	862.6	191	3.07	.3253
131.3	146	356.0	328.4	1190.5	862.2	190	3.05	.3274
133.3	148	357.1	329.5	1190.9	861.4	187	3.02	.3316
135.3	150	358.2	330.6	1191.2	860.6	185	2.98	.3358
140.3	155	360.7	333.2	1192.0	858.7	179	2.89	.3463
145.3	160	363.3	335.9	1192.7	856.9	174	2.80	.3567
150.3	165	365.7	338.4	1193.5	855.1	169	2.72	.3671
155.3	170	368.2	340.9	1194.2	853.3	164	2.65	.3775
160.3	175	370.5	343.4	1194.9	851.6	160	2.58	.3879
165.3	180	372.8	345.8	1195.7	849.9	156	2.51	.3983
170.3	185	375.1	348.1	1196.3	848.2	152	2.45	.4087
175.3	190	377.3	350.4	1197.0	846.6	148	2.39	.4191
180.3	195	379.5	352.7	1197.7	845.0	144	2.33	.4296
185.3	200	381.6	354.9	1198.3	843.4	141	2.27	.4400
190.3	205	383.7	357.1	1199.0	841.9	138	2.22	.4503
195.3	210	385.7	359.2	1199.6	840.4	135	2.17	.4605
200.3	215	387.7	361.3	1200.2	838.9	132	2.12	.4707
205.3	220	389.7	362.2	1200.8	838.6	129	2.06	.4852
245.3	260	404.4	377.4	1205.3	827.9	110	1.76	.5686
285.3	300	417.4	390.9	1209.2	818.3	96	1.53	.6515
485.3	500	467.4	443.5	1224.5	781.0	59	.94	1.062
685.3	700	504.1	482.4	1235.7	753.3	42	.68	1.470
985.3	1000	546.8	528.3	1248.7	720.3	30	.48	2.082

Questions

1. What is combustion?
2. What is one of the main factors in combustion?
3. Of what is air composed?
4. In what proportion are these two gases combined?
5. What is the principal constituent of coal and other fuels?
6. What other valuable constituent is contained in bituminous coal?
7. What is the usual temperature of a boiler furnace when in active operation?
8. About what should be the temperature of the escaping gases?
9. What two factors are indispensable in the economical use of coal?
10. What is heat?
11. What is the heat unit?
12. What is the mechanical equivalent of heat?
13. How many heat units are there in one pound of carbon?
14. How many heat units are there in one pound of hydrogen gas?
15. What is specific heat?
16. What is sensible heat?
17. What is latent heat?
18. Is the latent heat imparted to a body lost?
19. What is meant by the total heat of evaporation?
20. How much heat expressed in heat units is required to evaporate one pound of water from a temperature of 32° into steam at atmospheric pressure?
21. Name the two elements composing pure water.
22. In what proportion are these two gases combined in the formation of water?

23. Is perfectly pure water desirable for use in steam boilers?

24. What causes scale to form in boilers?

25. What proportion of mineral matter is usually found in water?

26. What is steam?

27. Of what does matter consist?

28. How does the application of heat to any substance affect its molecules?

29. In what particular manner does heat affect the molecules of water?

30. Is steam under pressure visible?

31. What is saturated steam?

32. What is dry steam?

33. What is superheated steam?

34. What is meant by the term total heat in steam?

35. What is meant by the density of steam?

36. What is meant by the volume of steam?

37. What is the weight of a cubic foot of water at 39.1° temperature?

38. What is the weight of a cubic foot of water at a temperature of 212°?

39. What is the boiling point of water in the open air at sea level?

40. At what temperature will water boil in a perfect vacuum?

41. What is meant by the relative volume of steam?

CHAPTER V

EVAPORATION TESTS

Evaporation tests, object of—Preparing for a test—Suggestions as to apparatus needed—Taking the temperature of the feed water—Precautions necessary to obtain accurate results—Duration of test—Feeding a boiler during a test—How to proceed if the boiler is fed by an injector—Determining the percentage of moisture in the steam—Moisture in the coal—Chimney draft—Draft gauge—Rules for determining the results of a test—"Equivalent evaporation," how to compute—Factors of evaporation—Boiler horse power.

Evaporation Tests. The object of making evaporation tests of steam boilers is primarily to ascertain how many pounds of water the boilers are evaporating per pound of coal burned; but these tests can and should be made to determine several other important points with reference to the operation of the boilers, as for instance: 1. The efficiency of the boiler and furnace as an apparatus for the consumption of fuel and the evaporation of water; whether this apparatus is performing its guaranteed duty in this respect, and how it compares with a known standard. 2. To determine the relative economy of different varieties of coal, also to determine the relative value of fuels other than coal, such as oil, gas, etc. 3. To ascertain whether or not the boilers as they are operated under ordinary every day conditions are being run as economically as they should be. 4. In case the boilers, owing to an increased demand for steam, fail to supply a sufficient quantity without forcing the fires, whether or not additional boilers are needed, or whether the trouble could

be overcome by a change of conditions in operating them.

As was stated in the chapter on boiler setting, every steam plant can and should be equipped with the necessary apparatus for making evaporation tests, and every engineer should take pride in making a good showing in the economical use of coal, and, be it said to their credit, the majority of engineers do this, although many of them are working under conditions that prevent them from doing all that they might desire along this line. Too many engineers are compelled to look after work entirely outside of and foreign to their vocation as engineers, often having to go to some distant part of the building to make repairs to some part of the machinery, leaving their boiler and engine to care for themselves for the time being, thus not only endangering the safety of property, but of life as well. But conditions are gradually changing for the better in this respect, and employers and owners of steam plants are coming more and more to recognize the fact that the engineer is something more than a mere handy man about a factory, in fact, that he has a distinct and responsible vocation to be fulfilled, viz., the safe and economical operation of the plant where the power comes from.

The author proposes to present in as brief a manner as possible a few simple suggestions and rules for the benefit of engineers who desire to make evaporation tests with a view of determining one or more of the points mentioned at the beginning of this chapter.

Tests for the last three purposes named can be made by the regular engineering force of the plant, but in case a controversy should arise between the maker of the boiler and the purchaser regarding the first men-

tioned point, viz., the guaranteed efficiency of the boiler or the furnace, the services of experts in boiler testing may be resorted to.

Preparing for a Test. All testing apparatus should be kept in such shape that it will not take three or four days to get it ready for making a test. On the contrary, it can be and should be always kept in condition ready for use, so that the preparations for making a test will occupy but a short time. A small platform scale sufficiently large for weighing a wheel-barrow load of coal should also be provided in addition to the apparatus referred to in Chapter II.

The capacity of each of the two tanks therein mentioned, and which are illustrated in Fig. 10, can be determined in two ways, either by measuring the cubical contents of each or by placing them one at a time on the scales, filling them with water to within a few inches of the top, and note the weight. Also make a permanent mark on the inside at the water level. The water should then be permitted to run out until within an inch or so of the outlet pipe near the bottom, where another plain mark should be made, after which the empty tank should be again weighed, then by subtracting the last weight from the first the exact number of pounds of water that the tank will contain between the top and bottom marks can be determined and a note made of it.

It is much more convenient to have each tank contain the same quantity of water, although not absolutely necessary. The tanks should also be numbered 1 and 2 respectively in order to prevent confusion in keeping a record of the number of tanks full of water used during the test. Care should be exercised to have the water with which the tanks are filled while on

the scale, at or near the same temperature as that at which it is to be fed into the boiler during the test. Otherwise there is liability of error owing to the variation in the weight of water at different temperatures. In order to guard against this, the capacity in cubic feet of each tank between the top and bottom marks should be ascertained by measuring the distance between the marks, also the diameter, or, if the tanks be square, the length of one side, after which the cubical contents can be easily figured and noted down. By knowing the capacity in cubic feet of each tank all possibility of error in the weight of feed water will be eliminated.

The scales for weighing the coal can be fitted with a temporary wooden platform large enough to accommodate a wheel-barrow, and after it has been balanced with the empty barrow on it, the record of weight of coal burned during the test can be easily kept.

The same barrow should be used throughout the test, and to save complications in estimating the weight, the same number of pounds of coal should be filled in the barrow each load. The coal passer will learn in a short time to fill the barrow to within a few pounds of the same weight each load by counting the shovelsful and the difference can easily be adjusted by having a small box of coal near the scale from which to take a few lumps to balance the load, or if there is too much coal in the barrow some of it can be thrown into the box.

At least two separate tally sheets should be provided, marked respectively coal and water, and the one for coal placed near the scale, and care should be taken that each load is tallied as soon as it is weighed. The tally sheet for water should be near the measuring

tanks and as soon as a tank is emptied it should be tallied. The temperature of the feed water should be taken at least every thirty minutes, or oftener if possible, from a thermometer placed in the feed pipe near the check valve, as described in Chapter II. The readings should be noted and, at the expiration of the test, the average taken.

If the object of the test is to ascertain the efficiency of the boiler and furnace it is absolutely necessary that the boiler and all its appurtenances be put in good condition, by cleaning the heating surface both inside the boiler and outside, scraping and blowing the soot out of the tubes if it be a return tubular boiler, and blowing the soot and ashes from between the tubes if it is a water tube boiler. All dust, soot and ashes should be removed from the outside of the shell and also from the combustion chamber and smoke connections. The grate bars and sides of the furnace should be cleared of all clinker, and all air leaks made as close as possible. The boiler and all its water connections should be free from leaks, especially the blow-off valve or cock. If any doubt exists as to the latter it should be plugged or a blind flange put on it. It is very essential that there should be no way for the water to leak out of the boiler, neither should any water be allowed to get into the boiler during the test except that which is measured by passing through the tanks.

The engineer making the test should know the number of square feet of grate surface and also the area of the heating surface in square feet. Rules for computing the latter are given in Chapter II. If the boiler is a water tube boiler the outside diameter of the tubes must be used in estimating the heating

surface. A correct knowledge of the above points is essential in making a test for determining any one of the four objects mentioned at the commencement of this chapter, but especially is it needed in conducting a test of the efficiency of the boiler and furnace.

In making an efficiency test it is essential that the boiler should be run at its fullest capacity from the beginning to the end of the test. Therefore arrangements should be made to dispose of the steam as fast as it is generated. If the boiler is in a battery connected with a common header, its mates can be fired lighter during the test, but if there is but the one boiler in use a waste steam pipe should be temporarily connected through which the surplus steam, if there is any, can be discharged into the open air through a valve regulated as required. Before starting the test the boiler should be thoroughly heated by having been run several hours at the ordinary rate. The fire should then be cleaned and put in good condition to receive fresh coal.

At the time of beginning the test the water level should be at or near the height ordinarily carried and its position marked by tying a cord around one of the guard rods of the gauge glass, and, to prevent all possibility of error, the height of the water in the glass should be measured and a note made of it. Note also the time that the first lot of weighed coal is fed to the furnace and record it as the starting time. The steam pressure should be noted at the beginning of the test and at regular intervals during the progress of the test in order that the average pressure may be obtained.

At the close of the test all of the above conditions should be as nearly as possible the same as at the

beginning; the quantity and condition of the fire should be the same, also the steam pressure and water level. This can be accomplished only by careful work towards the close of the test.

During the progress of the test care should be exercised to prevent any waste of coal, especially in cleaning the fire. The ash made during the test must not be wet down until after it is weighed, as in all calculations for combustible and non-combustible matter in the coal the ash should be dry.

The duration of the test should be at least ten hours if it is possible to continue it for that length of time. The feed pump should be kept running at such speed as will supply the water to the boiler as fast as it is evaporated, and no faster. If at the close of the test a portion of water is left in the last tank tallied it can be measured and deducted from the total. And if any weighed coal is left on the floor it should be weighed back and deducted from the total weight. If the boiler is fed by an injector instead of a pump during the test, the injector should receive steam directly from the boiler under test through a well protected pipe. Also, the temperature of the feed water should be taken from the measuring tanks, or at least from the suction side of the injector, for the reason that the water in passing through the injector receives a large quantity of heat imparted to it by live steam directly from the boiler. Therefore the temperature of the water after it leaves the injector would not be a true factor for figuring the evaporation.

Determination of the Percentage of Moisture in the Steam. This is an important point in estimating the results of an evaporation test for the reason that each pound weight of moisture in the steam as it leaves the

boiler represents a pound of water that has not been evaporated into steam, and should therefore be deducted from the total weight of water fed into the boiler during the test.

The steam should be tested for moisture by taking samples of it from the steam pipe or header as near the boiler as possible in order to guard against additional moisture caused by condensation. For making expert boiler tests for scientific and other purposes, an instrument called a calorimeter is used for ascertaining the quantity of moisture in the steam. But most engineers are not so fortunate as to possess one of these instruments, nor even to induce their employers to purchase one, therefore space will not be taken up in describing it here. A method of testing the quality of the steam by noting the appearance of a small jet blowing into the atmosphere is mentioned near the close of Chapter IV, which in the absence of a calorimeter would answer very well for ordinary purposes.

Moisture in the Coal. This can generally be obtained from the reports of the geologist of the state in which the coal is mined or from the dealer, although the former is the most reliable. The percentage of moisture must be deducted from the total weight of coal in figuring the weight of combustible.

Measuring the Chimney Draft. A good draft is indispensable for obtaining economical results in an evaporation test. The draft can be easily regulated by a damper to suit the conditions. Chimney draft is ordinarily measured by a draft gauge connected with the smoke flue near the chimney. The usual form of draft gauge is a glass tube bent in the shape of the letter U. (See Fig. 12.) One leg is connected to the flue by a

small rubber hose, while the other is open to the atmosphere. The tube is partly filled with water, which will, when there is no draft, stand at the same height in both legs. When connected to the chimney or flue the suction will cause the water in the leg to which the hose is attached to rise, while the level of the water in the other leg will be equally depressed, and the extent of the variation in fractions of an inch is the measure of the draft. Thus the draft is referred to as being .5, .7 or .75 inches. The draft should not be less than .5 inches in any case to insure good results.

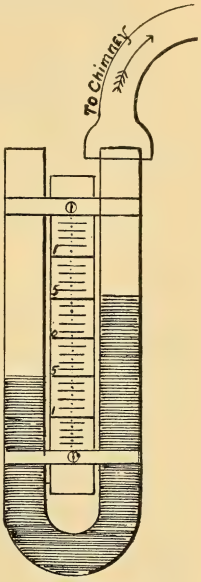


FIGURE 12.

Having thus successfully conducted the test to its close, and being armed with all the data heretofore noted, the engineer is now ready to compute the results.

If the test is made for the purpose of determining the efficiency of the boiler and setting as a whole, including grate, chimney draft, etc., then the result must be based upon the number of pounds of water evaporated per pound of coal. This latter phrase includes not only the purely combustible matter in the coal, but the non-combustible also, as ash, moisture, etc. Some varieties of western coal contain as high as 12 to 14 per cent. of moisture, and the ability of the furnace

to extract heat from the mass is to be tested, as well as the ability of the boiler to absorb and transmit that heat to the water. Therefore the efficiency of the boiler and furnace =

$$\frac{\text{Heat absorbed per pound of coal.}}{\text{Heating value of one pound of coal.}}$$

If the test is to determine the efficiency of the boiler itself as an absorber of heat, then the combustible alone must be considered in working out the final result. Thus,

Efficiency of boiler =

$$\frac{\text{Heat absorbed per pound of combustible.}}{\text{Heating value of one pound of combustible.}}$$

When making a series of tests for the purpose of comparing the economical value of different varieties of coal the conditions should be as nearly uniform as possible; that is, let the tests be made under ordinary working conditions and with the same boiler or boilers, and if possible with the same fireman.

The following is a record of one of many evaporation tests made by the author, and is introduced here for the purpose of illustrating methods of computing the results to be obtained from the various data. The rather large quantity of coal burned per square foot of grate surface per hour (25 lbs.) is owing to the fact that the boiler was run to its full capacity, the coal burning clean and forming no clinker. The chimney draft also was exceptionally good, giving a large unit of evaporation per square foot of heating surface per hour. The low temperature of the escaping gases is due to the fact that they were returned over the top of the boiler before passing to the chimney.

Date of test.....
Duration of test, 12 hours.
Boiler, return tubular, 72 in. diameter, 18 ft. long, 62-4½ in. tubes.

Kind of coal, Pocahontas; average steam pressure	85	lbs.
Weight of coal consumed	11,100	"
Weight of water apparently evaporated	107,187	"
Weight of dry ash returned .....8.1 per cent. =	900	"
Moisture in the coal.....2.0 " =	222	"
Moisture in the steam.....1.0 " =	1,071	"
Dry coal corrected for moisture	10,878	"
Weight of combustible	9,978	"
Water corrected for moisture in the steam	106,116	"
Water evaporated into dry steam, from and at 212°	117,788	"
Water evaporated per lb. of coal, actual conditions	9.65	"
Water evaporated per lb. of coal, from and at 212°	10.61	"
Water evaporated per lb. of combustible, from and at 212°	11.81	"
Water evaporated per lb. of dry coal, from and at 212°	10.82	"
Water evaporated per hr. per sq. ft. of heating surface	6.22	"
Coal burned per sq. ft. of grate surface per hour	25	"
Horse power developed by boiler during test	284.5	
Temperature of feed water, average	141°	
Temperature of chimney gases, average	400°	
Square feet of grate surface	36	
Square feet of heating surface	1576	
Ratio of grate surface to heating surface	43.7	

The results obtained will be taken up in their regular order beginning with, first, water evaporated into dry steam from and at 212°. As it may be of benefit to some, a short definition of the meaning of the above expression is here given.

The term "equivalent evaporation," or the evaporation from and at 212°, assumes that the feed water enters the boiler at a temperature of 212° and is evaporated into steam at 212° temperature and at atmospheric pressure. As for instance, if the top man hole plate were left out or some other large opening in the steam space allowed the steam to escape into the atmosphere as fast as it was generated. Owing to the variation in the temperatures of the feed water used in different tests, and also the variation in the steam pressure, it is absolutely necessary that the

results of all tests be brought by computation to the common basis of 212° in order to obtain a just comparison.

The process by which this is done is as follows: Referring to the record of the test it is seen that the steam pressure average was 85 lbs. gauge pressure, or 100 lbs. absolute, and that the temperature of the feed water was 141°. Referring again to Table No. 5, physical properties of steam, it will be seen that in a pound of steam at 100 lbs. absolute pressure there are 1,181.8 heat units, and in a pound of water at 141° temperature there are 109.9 heat units. It therefore took 1181.8 – 109.9 = 1071.9 heat units to convert one pound of feed water at 141° into steam at 85 lbs. pressure. To convert a pound of water at 212° into steam at atmospheric pressure, and 212° temperature requires 965.7 heat units, and the 1,071.9 heat units would evaporate 1,071.9 ÷ 965.7 = 1.11 lbs. water from and at 212°. The 1.11 is the factor of evaporation for 85 lbs. gauge pressure and 141° temperature of feed water, and by multiplying "water corrected for moisture in the steam" (see record of test), 106,116 lbs., by 1.11, the weight of water which could have been evaporated into steam from and at 212°, is obtained, which is 117,788 lbs. The factor of evaporation is based upon the steam pressure and the temperature of the feed water in any test and the formula for ascertaining it is as follows: $\text{Factor} = \frac{H - h}{965.7}$, in which H = total heat in the steam, and h = total heat in the feed water. It is used in shortening the process of finding the evaporation from and at 212°, and Table No. 6 gives the factor of evaporation for various pressures and temperatures.

Table 6

Factors of Evaporation

Feed Water Temperature	Gauge Press. 50 lbs.	Gauge Press. 60 lbs.	Gauge Press. 70 lbs.	Gauge Press. 80 lbs.	Gauge Press. 90 lbs.	Gauge Press. 100 lbs.	Gauge Press. 110 lbs.	Gauge Press. 120 lbs.	Gauge Press. 140 lbs.
212°	1.027	1.030	1.032	1.035	1.037	1.039	1.041	1.043	1.047
200°	1.039	1.042	1.045	1.047	1.050	1.052	1.054	1.056	1.059
191°	1.049	1.052	1.054	1.057	1.059	1.061	1.063	1.065	1.069
182°	1.058	1.061	1.064	1.066	1.069	1.071	1.073	1.075	1.078
173°	1.067	1.070	1.073	1.076	1.078	1.080	1.082	1.084	1.087
164°	1.077	1.080	1.083	1.085	1.087	1.090	1.091	1.093	1.097
152°	1.089	1.092	1.095	1.098	1.100	1.102	1.104	1.106	1.109
143°	1.099	1.102	1.105	1.107	1.109	1.111	1.113	1.115	1.119
134°	1.108	1.111	1.114	1.116	1.119	1.121	1.123	1.125	1.128
125°	1.118	1.121	1.123	1.126	1.128	1.130	1.132	1.134	1.137
113°	1.130	1.133	1.136	1.138	1.140	1.143	1.145	1.146	1.150
104°	1.138	1.142	1.145	1.148	1.150	1.152	1.154	1.156	1.159
95°	1.149	1.152	1.154	1.157	1.159	1.161	1.163	1.165	1.169
86°	1.158	1.161	1.164	1.166	1.169	1.171	1.173	1.174	1.178
77°	1.167	1.170	1.173	1.176	1.178	1.180	1.182	1.184	1.187
65°	1.180	1.183	1.186	1.188	1.190	1.192	1.194	1.196	1.200
56°	1.189	1.192	1.195	1.197	1.200	1.202	1.204	1.206	1.209
47°	1.199	1.201	1.204	1.207	1.209	1.211	1.213	1.215	1.218
38°	1.208	1.211	1.214	1.216	1.218	1.220	1.222	1.224	1.228

Second, water evaporated per pound of coal actual conditions = water apparently evaporated divided by coal consumed = 9.65 lbs. No accurate estimate regarding the quality of the coal or the efficiency of the boiler can be made from this figure (9.65 lbs.). It can be used, however, in estimating the cost of fuel for generating the steam; as, for instance, if the boiler is supplying steam to an engine that uses 30 lbs. of steam per horse power per hour, it will require $30 \div 9.65 = 3.1$ lbs. of coal per horse power per hour; the "actual conditions" under which the boiler is being operated being the pressure of steam required by the engine and the temperature of the feed water.

Third, water evaporated per pound of coal from and at 212° = water evaporated into dry steam from and at 212° divided by coal consumed = 10.61 lbs. This figure is the proper one to use in comparing the relative economic values of different varieties of coal tested with the same boiler or boilers.

Fourth, water evaporated per pound of combustible from and at 212° = water evaporated into dry steam from and at 212° divided by weight of combustible = 11.81 lbs. This result is the one to be used for ascertaining the efficiency of the boiler, and the percentage of efficiency is found by dividing the heat absorbed by the boiler per pound of combustible by the heat value of one pound of combustible. The average heat value of bituminous and semi-bituminous coals is not far from 15,000 heat units per pound of combustible. In the evaporation of 11.81 pounds of water from and at 212° the heat absorbed was $11.81 \times 965.7 = 11,404.9$ heat units. The efficiency of the boiler therefore was $\frac{11,404.9 \times 100}{15,000} = 76$ per cent.

In like manner to ascertain the efficiency of the boiler and furnace as a whole, the water evaporated from and at 212° per pound of coal is taken. Thus, $10.61 \times 965.7 = 10,246$ heat units absorbed from each pound of coal. Now assuming that there were 13,500 heat units in each pound of the coal used in the test, the per cent of efficiency of boiler and furnace was

$$\frac{10,246 \times 100}{13,500} = 75.9.$$

Fifth, water evaporated per pound of dry coal from and at 212° = water evaporated into dry steam from and at 212° divided by coal corrected for moisture. Thus, $117,788 \div 10,878 = 10.82$ lbs. This result is useful for calculating the results of tests of the same grade

of coal, but differing in the degree of moisture in each.

Sixth. Boiler horse power. The latest decision of the American Society of Mechanical Engineers (than whom there is no better authority) regarding the horse power of a boiler is as follows: "The unit of commercial horse power developed by a boiler shall be taken as 34½ units of evaporation per hour. That is, 34½ lbs. of water evaporated per hour from a feed temperature of 212° into steam of the same temperature. This standard is equivalent to 33,317 B. T. U. per hour. It is also practically equivalent to an evaporation of 30 lbs. of water from a feed water temperature of 100° F. into steam of 70 lbs. gauge pressure."

According to this rule the horse power developed by the boiler during the test under consideration = water evaporated into dry steam from and at 212°, 117,788 lbs ÷ 12 hrs. ÷ 34.5 = 284.5 horse power.

Questions

1. What is the primary object of an evaporation test?
2. Name four other important points which can be determined by evaporation tests.
3. In making a test of the efficiency of the boiler and furnace, what precautions should be observed?
4. How is the heating surface of water tube boilers estimated?
5. What length of time should a test be conducted?
6. In case the boiler is fed by an injector, what precautions are necessary?
7. If the steam contains any moisture, what should be done?
8. How is the weight of combustible determined?

9. What is a calorimeter, and for what purpose is it used?

10. By what other method may the moisture in the steam be estimated approximately?

11. What should be done with the percentage of moisture in the coal?

12. How is the chimney draft measured?

13. Describe a draft gauge.

14. Give the formula for ascertaining the efficiency of the boiler and setting.

15. If the test is to determine the efficiency of the boiler alone, what factors are used?

16. If a series of tests is made for comparing different varieties of coal, what should be done?

17. What is meant by equivalent evaporation?

18. Why should the results of all tests be computed from and at 212°?

19. What is a factor of evaporation?

20. How is it determined?

21. What is a boiler horse power?

22. How many heat units per hour is this equivalent to?

CHAPTER VI

VALVES AND VALVE SETTING

Valves and valve setting—Importance of correct adjustment—The D slide valve—Single valve engines—Four valve engines—Various positions of the slide valve during one revolution—Relative positions of the crank pin and eccentric during the stroke—Valve diagrams—Placing the engine on the center—Adjusting the length of eccentric rod—Measuring the inside and outside lap—Setting the valve—Fixed cut off engines—Variable automatic cut off—Factors affecting the distribution of the steam—Why the four valve engine is the most economical—Description of corliss valves and valve gear and directions for adjusting the same.

Valves and Valve Setting. It goes without saying that every man who aspires to be an engineer should endeavor to thoroughly acquaint himself with the principles governing the action of valves as well as the details of valve setting. But it must be remembered that this knowledge can not be acquired in a day or a week, or even months. True, a man may be able to learn some of the alphabet of valve lore in a comparatively short time, but the more practical experience he has in the work the more will he realize the supreme need of mastering all the details of the process.

The common D slide valve, simple as it appears, is capable of furnishing problems over which savants have puzzled themselves.

The development of the full amount of power of which the engine is capable, its efficiency and economical use of steam, and its regular and quiet action are, in the largest degree, dependent upon the correct adjustment of its valve or valves.

There are many different types of valves for controlling the admission and release of steam to and from the cylinders of engines, but the basic principles governing the adjustment of all, whether slide, poppet, rotative, piston, etc., are exemplified in the action of the common D slide valve, viz., the admission of the steam to the cylinder, its cut off and release, and the closure of the exhaust, each and all of which events are to take place at the proper moment during one stroke of the piston.

In order to properly perform these important functions the valve must have lead and lap. The various terms relating to valve action are plainly defined in Chapter VIII on "Definitions," and it is unnecessary to repeat them here. If the outside lap is increased admission will be later and cut off earlier, and if it be desired to keep the lead the same it will be necessary to move the eccentric forward, which will make the other events, cut off, release, and compression, earlier also. If the inside lap is increased the result will be an earlier closing of the exhaust and increased compression.

These propositions refer mainly to engines of the single valve variety in which one valve controls the admission and distribution of the steam for both ends of the cylinder. In engines of the four valve type, having a separate steam and exhaust valve for each end of the cylinder, each individual valve may be adjusted independently of the others, as will be explained later on, and in the case of engines having separate eccentrics, one for the steam and one for the exhaust valves, the adjustment becomes still more perfect.

We will first study the action of the D slide valve by

referring to Fig. 13, which is a sectional view of a valve, valve seat and ports. The valve is represented at mid travel or in its central position. S P, S P are the steam ports, and E P is the exhaust port. The projections marked X at each foot of the arch inside

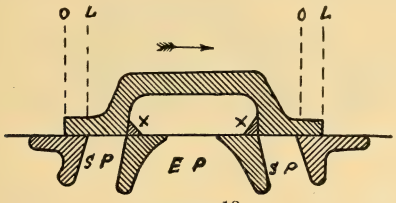


FIGURE 13.

the valve, represent inside lap and may be added to or taken from the inside edges of the valve, according as more or less compression is desired. The dotted lines, O L, O L represent outside lap.

Motion is imparted to the valve through the medium

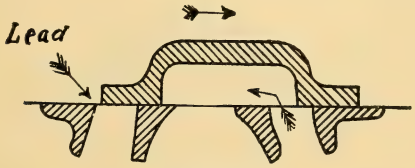


FIGURE 14.

of the eccentric. If the valve had neither lap nor lead the position of the eccentric on the crank shaft would be just 90° or one-quarter of a circle ahead of the crank, but as more or less lap as well as lead is required, it becomes necessary to move the eccentric

still farther ahead of the crank, and this farther advance is termed angular advance, lap angle for lap and lead angle for lead.

Assuming the piston to be at the end of the stroke towards the crank, in other words, the engine to be

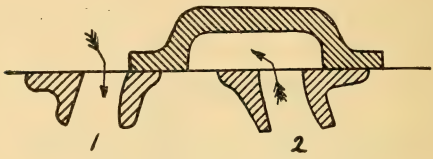


FIGURE 15.

on the dead center, the first function of the valve is lead or admission, illustrated by Fig. 14. Owing to the valve having both lap and lead, the position of the highest point of the eccentric will be assumed in this case to be 120° ahead of the crank, the position of the latter being at 0°.

Exhaust opening has also occurred at the opposite

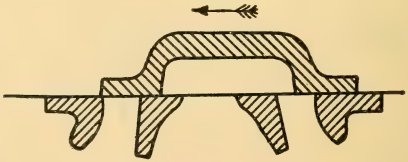


FIGURE 16.

end of the cylinder. The second function is full port opening, Fig. 15, the crank having moved through 60° and the eccentric is now at 180°, the farthest point of its throw in that direction, the valve being at the end of its travel. At this point it might be well to note a

matter about which some persons are liable to become confused, simple as it is, viz., that the travel of a slide valve equals twice the port opening plus twice the outside lap. For instance, suppose the width of each steam port to be 1¼ in. and the outside lap to be 1 in. In Fig. 15 the valve is at the extreme end of its travel

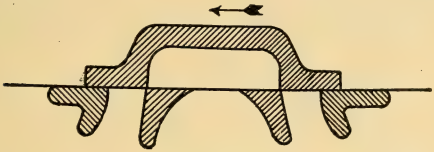


FIGURE 17.

towards the right and is about to return. It first covers port number one = 1¼ in. Next it moves to mid travel lap number one = 2¼ in. Its next move is lap number two = 3¼ in., and lastly it uncovers port number two = 4½ in., which is its travel.

To return to the third function of the valve or cut

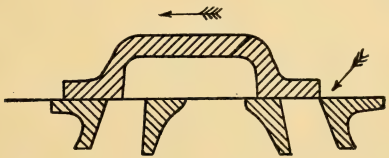


FIGURE 18.

off, Fig. 16. The crank has now traversed 120° and the highest point of the eccentric is at 60° on the return circle, a point equivalent to 240° of the circle described by the crank.

The fourth function is when compression begins at the head end of the cylinder, Fig. 17. The crank is

now at 150°, the piston being near the end of the stroke and the eccentric has reached 90° of the return circle or three-quarters of the crank circle, while the crank has still to travel 30° in order to complete the first one-half of its circle. At this point we can study the effect of inside lap, because if the valve has no inside lap, release on the crank end will begin almost at the same moment that compression takes place at the head end,

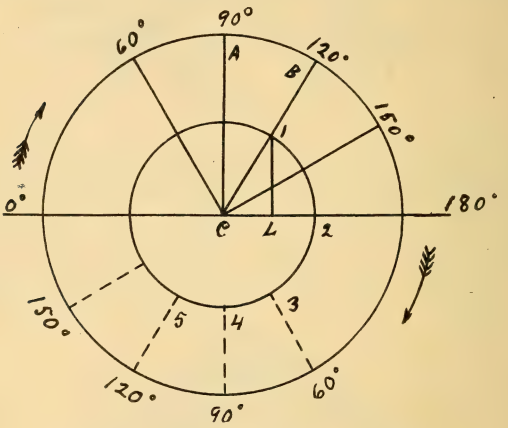


FIGURE 19.

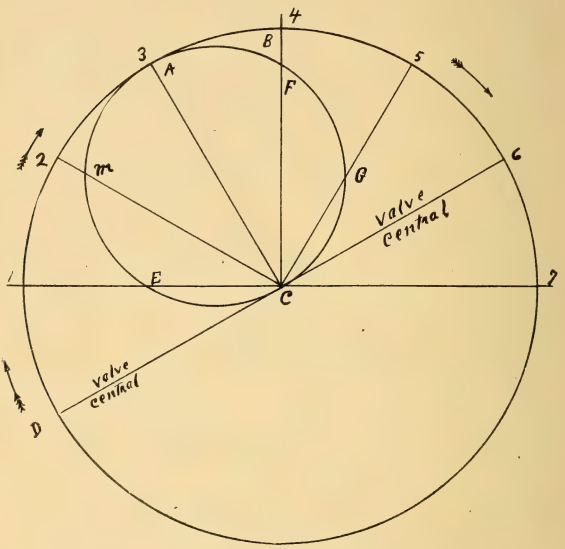
but by adding inside lap, compression can be caused to take place earlier and release later.

The next event is admission at the head end of the cylinder, Fig. 18. The crank has now arrived at 180°, having completed one-half of a revolution; the piston is at the end of the stroke, and the eccentric is at 120° on the return path. Fig. 19 serves to better illustrate the relative positions of the crank pin and

eccentric during the stroke. The inner circle represents the path described by the high point of the eccentric, and the large circle that of the crank pin. The radius C 2 of the small circle represents the throw of the eccentric, and the distance C L is the lap of the valve plus the lead. The point of intersection of the vertical line, L 1, with the eccentric circle locates the position of the highest point of the eccentric, and the line C B, drawn from the center of the crank shaft through this point, indicates the angular advance, which in this case is 30° represented by the angle A B C. The figures 1, 2, 3, 4, 5 indicate the position of the high point of the eccentric at the moment of each function of the valve. The action of the valve can be more graphically illustrated by means of valve diagrams, of which there are several different kinds, notably the Bilgram and Zeuner. The Zeuner diagram will be made use of in this instance.

Fig. 20 shows the total movement of the valve, regardless of lap and lead. First draw line C 1 to represent the center line of the engine. Next draw line C 4 perpendicular to the line of centers, with C as the center of the crank shaft. The radius of the semicircle D, 1, 2, 3, 4, 5, 6 equals the radius of eccentricity. Line C D represents the position of the crank when the valve is at mid travel or in its central position, D being the location of the crank pin. Referring back to Fig. 13 the valve is there shown in its central position and supposed to be moving in the direction of the arrow in order to admit steam to the crank end of the cylinder. Again referring to Fig. 20, draw line C A in such a position that the angle A B C will equal the angular advance of the eccentric, which we will assume in this case to be 30°. This will bring the

high point of the eccentric at B while the crank, as before stated, is at D. Next using line C A as the diameter draw a circle about it called the valve circle.



Valve Travel = 4½ in
Radius of Eccentricity = 2¼ in

FIGURE 20.

Now suppose the crank to be turning in the direction of the arrows. At position D the crank line is just about to cut into the valve circle, the valve being central. When the crank gets to position 1 the valve

has moved the distance C E. When the crank is at 2 the valve has moved the distance C M, and when the crank arrives at 3 the valve has moved to the limit of its travel from its central position and it now begins the return movement. The motion of the valve is comparatively slow at this point for the reason that the high point of the eccentric is now passing the center at 7. The distance the valve has moved backward while the crank has moved from 3 to 4 is the distance B F, while F C represents its distance from the central position, and G C the same when the crank is at 5. When the crank arrives at 6 and its line has left the valve circle, the valve is again central. Fig. 20 merely shows the movement of the valve through one-half of its travel without giving any details regarding port openings, cut off, etc.

In Fig. 21 the influence of outside lap is delineated. According to the dimensions of the valve under consideration the outside lap is one inch. The diagram is drawn precisely as in Fig. 20, and in addition strike an arc representing the outside lap, using C as the center with a radius equal to the outside lap. As before, the crank is at D and the valve central. When the crank has moved to E and its line cuts the intersection of the outside lap and valve circles, the valve has moved the distance C H, just equal to the outside lap, and the port begins to uncover at this point. Then by the time the crank gets to the center, 1, the port is open the distance L O, which is the lead, in this case $\frac{1}{8}$ in. This position of the valve is shown in Fig. 14.

The position of the crank when cut-off takes place is ascertained by drawing a line, C G 5, through the intersection of the outside lap and valve circles, where the valve is on its return movement (see Fig. 16). Thus

far no account has been taken of release and compression, and in order to determine the position of the crank when these events occur it will be necessary to

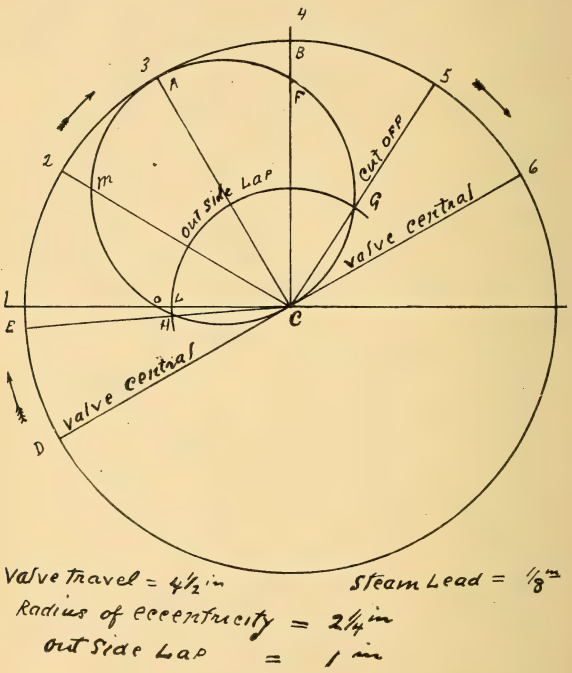


FIGURE 21.

draw the valve circle for the opposite movement of the valve, for be it remembered that the movement of the valve so far considered has been only one-half of its

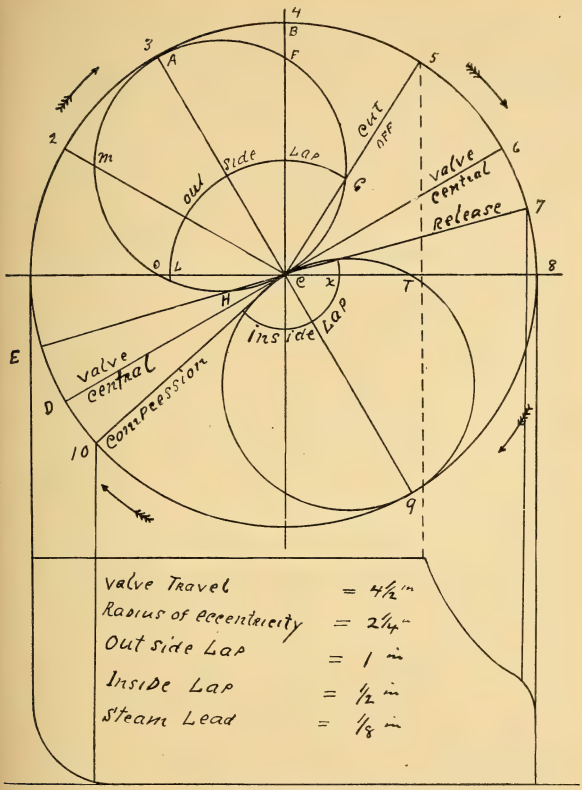


FIGURE 22.

travel; that is, it has moved from its central position towards the head end of the cylinder and back again. We have seen how it has thus performed the functions

of admission, full port opening and cut off for the crank end of the cylinder, and now by referring to Fig. 22 it will be seen at what point of the stroke the remaining events, viz., release and compression occur.

Draw a second valve circle, Fig. 22, diametrically opposite the first. Also draw an arc with a radius equal to the inside lap, which in this case is assumed to be one-half inch. When the crank gets to the position 7 its center line cuts the intersection of the inside lap and valve circles and release begins. When the crank arrives on the center 8, the valve has moved the distance C T from central position; but C X of this distance has been occupied by the inside lap, therefore the lead on the exhaust is represented by the distance X T. When the crank on its return stroke arrives at the position marked 10, its line again cuts the intersection of the inside lap and valve circles and compression takes place, as in Fig. 17. By dropping perpendiculars from the positions of the crank at 1, 5, 7 and 10 an indicator diagram may be drawn showing the performance of an engine with this style of valve.

Fig. 23 shows the effect of decreasing the angular advance, that is, setting the eccentric back towards the crank. In this instance the eccentric is set back 10°, thus making the angle of advance 20° instead of 30° as before. The full lines represent the new angle, while the dotted circles and lines indicate the valve and its movements as drawn at first. A shows the original point of admission and A′ the position of the crank when admission takes place with the lesser angle of advance. Similarly R and R′ show the old and new points of release, and C and C′ the compression The two different points of cut off are also indicated. It

will be observed that all of these events occur later and the lead also is diminished.

In locomotives, and also in some types of adjustable cut off engines, the travel of the valve may be varied at will, and the effect of decreasing the valve's travel

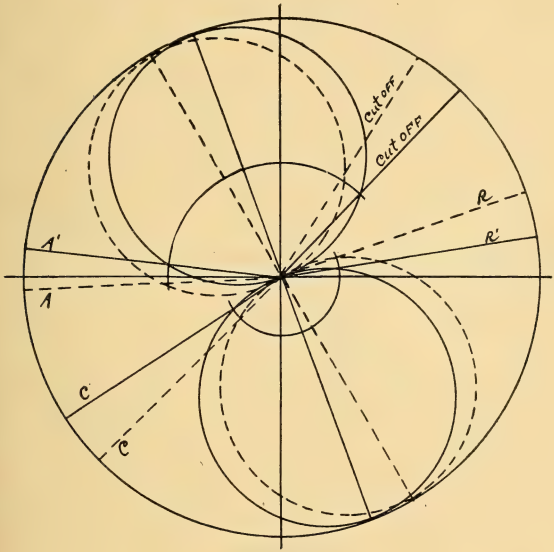


FIGURE 23.

is illustrated by Fig. 24, the full lines showing the decreased travel and its influence, and the dotted lines showing the original. Admission and release occur later, while cut off and compression take place earlier, and the lead is less. The travel of the valve as indicated

in Fig. 24 has been decreased one inch, making it 3½ in. in place of 4½ in. as before.

Fig. 25 shows the result of increasing the outside lap. The lap has been increased in this case from 1 in., as originally drawn, to 1¼ in. as indicated by the

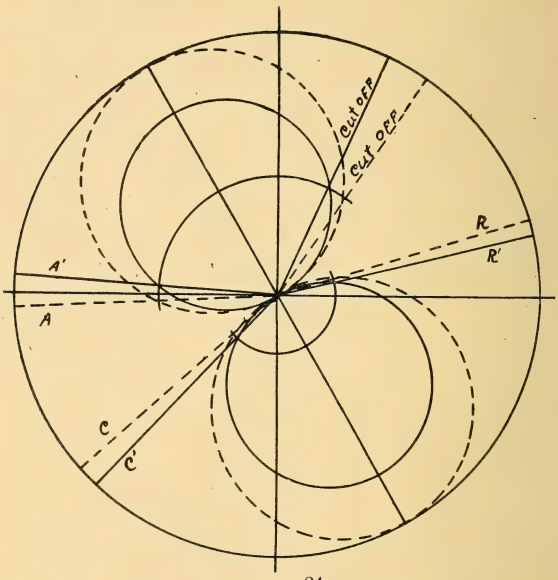


FIGURE 24

full lines, while the dotted lines show the lap as it was before being changed. The effect of this change is to cause less lead, a later admission and an earlier cut off, but compression and release are not affected for the reason that these latter events are controlled by the inside lap, which has not been changed.

In Fig. 22 the valve is shown as cutting off the steam when the crank has completed 120° or two-thirds of the half revolution, but the point of cut off on the indicator diagram shows that the piston has traveled $\frac{3}{4}$ of the stroke. This discrepancy is due to the obliquity

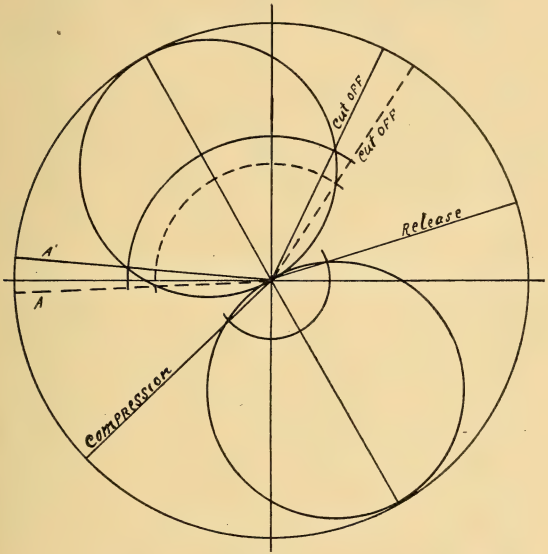


FIGURE 25.

of the connecting rod, as it will be seen by looking at the valve diagram, Fig. 22, that the crank must travel farther to complete the stroke from this point than the piston does. In order to cause the valve to cut off earlier, say at one-half stroke, it will be necessary to do one of two things, either to increase the outside

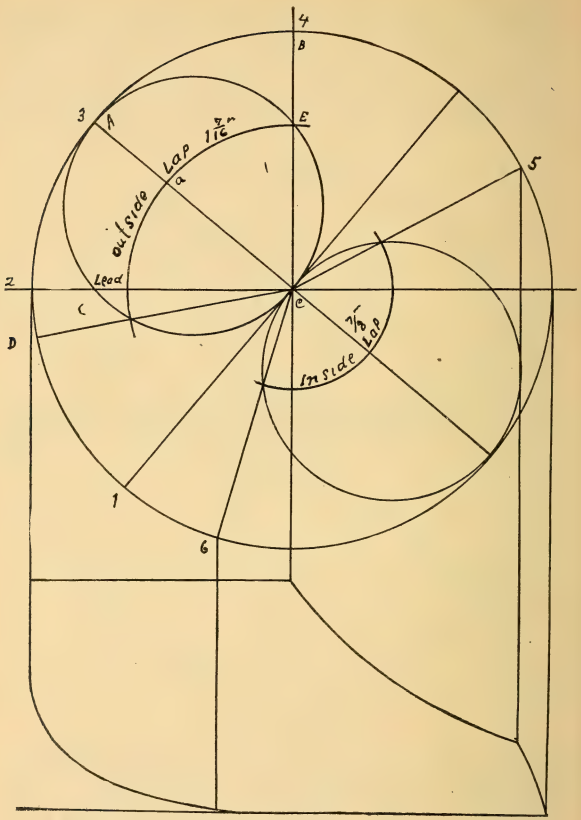


FIGURE 26.

lap, which would have a tendency to cause admission to occur too late, or the angle of advance may be

increased sufficient to cause cut off to take place at half stroke, but to do this alone would cause admission to occur too early. Therefore the proper thing to do is to increase both the angle of advance and the outside lap. Fig. 26 shows how this can be done without decreasing the travel of the valve. The angle of advance, A B C, is now 50°, where before it was 30°, as in Fig. 22.

The valve is central when the crank is at position 1; the high point of the eccentric being at point 4. The outside lap which before was 1 in. has had $\frac{7}{16}$ in. added to it, making it $1\frac{7}{16}$ in. When the crank gets to D the port is just commencing to open, and with the crank on the center at 2, the lead is $\frac{1}{4}$ in.

It will readily be seen at this point that by increasing the outside lap still more the lead can be diminished, and the point of cut off made still earlier, but this would result in a still further reduction of the power of the engine, which has already been considerably reduced, as shown by the diminished area of the indicator diagram as compared with the one in Fig. 22. When the crank gets to position 3 the valve has reached the limit of its travel, and the port is open the distance A a, which is as far as the outside lap will permit. With the crank at point 4 cut off occurs. But with the increased angular advance and the inside lap remaining as it was before, viz., $\frac{1}{2}$ in., release would occur too early. Therefore it will be necessary to increase the inside lap sufficient to cause release and compression to take place at as near the proper points as possible. In this instance $\frac{3}{8}$ in. has been added, making the inside lap $\frac{7}{8}$ in., and release takes place with the crank at position 5, while compression begins at 6. These points may

also be changed by simply adding to or decreasing the inside lap.

It should be noted that in the foregoing discussion of valve gear it is understood that the valve stem moves in the same direction as the eccentric rod, that is, the direction of motion is not reversed by a rocker arm interposed between the eccentric and the valve.

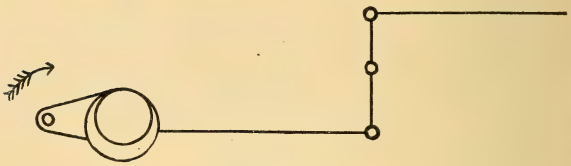


FIGURE 27.

In case there should be a rocker arm connected so as to reverse the motion and thereby cause the valve to move opposite to the eccentric rod, it will be necessary to set the eccentric behind the crank, as in Fig. 27.

Most engines are fitted with a rocker arm for transmitting the motion of the eccentric to the valve stem,

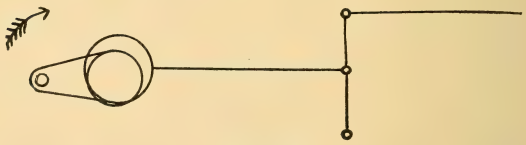


FIGURE 28.

but the usual practice is to attach them so that the direction of motion is not reversed, as in Fig. 28

The first step in the operation of valve setting is to place the engine on the dead center, which means that

the piston is at the end of the stroke, and the centers of the main shaft, crank pin and crosshead pin, or wrist pin as it is sometimes called, are in line (see Fig. 31). When moving the engine to place it on the center it should always be turned in the direction in which it is to run. This is to guard against any errors which might result from lost motion or looseness in the reciprocating parts. Turn the fly wheel around until the crosshead is almost to the end of the stroke, say within a half inch of it, as at A, Fig. 29. Then with a

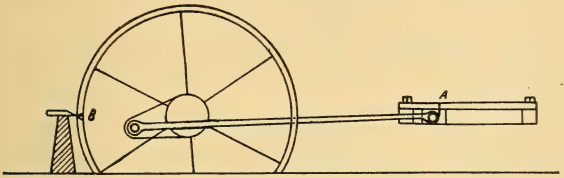


FIGURE 29.

steel scriber or penknife mark the location of the crosshead on the guides A, also provide a secure resting place upon the floor of the engine-room for a marker to be placed against the rim of the wheel. This rest should be firmly fastened to the floor in order that its position may not be changed during the operation of valve setting. Place the marker against the wheel as at B and mark the point with a center punch or cold chisel. Next turn the engine carefully until the crosshead completes the stroke and moves back on the return stroke until the mark A is in line again. Make another mark on the rim of the wheel opposite the marker at C. This position of the engine is shown in Fig. 30, and it will be seen that the crank is now as much above the center as it was below in Fig.

29. Now with a pair of large dividers ascertain the middle or half distance between marks B and C and put another mark, D, at this point. Then turn the

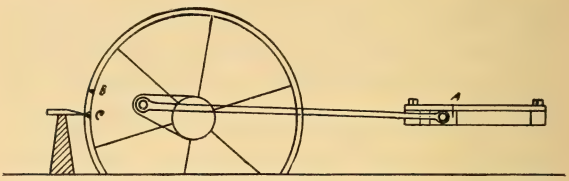


FIGURE 30.

engine a complete revolution until mark D comes opposite the pointer, Fig. 31, and the engine will be on the true center.

At this point the question may arise, why not simply reverse the motion and back the wheel up until the mark D is in line with the marker? The answer is,

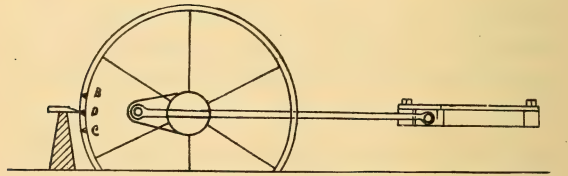


FIGURE 31.

that while this would undoubtedly save considerable labor, yet it would almost certainly result in an error, on account of the lost motion of the moving parts which would permit of considerable movement of the wheel before any movement of the crosshead would take place if the wheel was turned back. The result would be that when mark D came to be opposite to the

pointer, the crank would not be on the true center. The next move is to see that the eccentric rod is adjusted to the proper length. If there is a rocker arm, connect the eccentric rod in its proper place, leaving the valve rod disconnected for the time being.

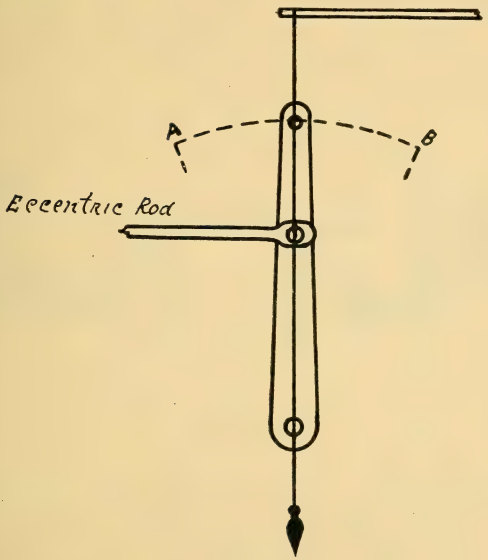


FIGURE 32.

Then adjust the length of the rod so that when the eccentric is turned around on the shaft the rocker arm will vibrate equal distances on each side of a plummet line suspended through the center of the pin upon which the arm turns, as in Fig. 32. Before connecting

the valve rod the valve should be put in its central position and marked. To do this it will be necessary to first ascertain the outside lap.

The most accurate method of doing this is to take the valve out and measure the distances between the outside edges of the steam ports as at B, Fig. 33. Then measure the width of the valve from edge to edge as at A. Then A – B ÷ 2 = the outside lap. For instance, A = 8.5 in., B = 6.5 in. Then 8.5 – 6.5 = 2, and 2

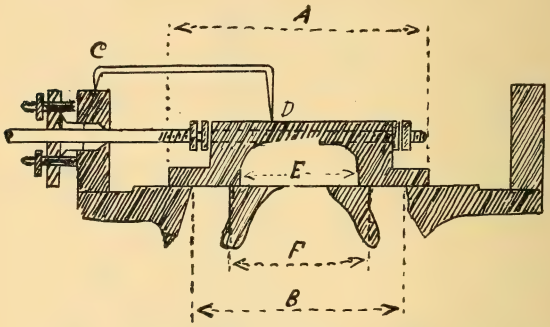


FIGURE 33.

divided by 2 = 1 in., which is the lap. The inside lap should also be measured at this point for convenience, and the measurements preserved for future reference. The inside lap is ascertained by measuring the distance between the inside edges of the ports and the distance across the arch of the valve from one inside edge to the other (see Fig. 33) and dividing the difference by 2. For instance, the distance F is 4 in., and E is 3 in.; then $4\frac{3}{2} = .5$ in., making the inside lap ½ in.

To place the valve central, measure the width of the

outside lap each way from the outside edges of the steam ports and mark the points on the valve seat with a sharp lead pencil. Then place the valve with edges on the marks and it will be central. To insure accuracy measurements should also be taken from the outside edges of the steam ports to the ends of the seats. Having fixed the valve in its central position, replace the stem and if it is secured in the valve by nuts, as in Fig. 33, care should be taken to leave a little play for the valve between the nuts, otherwise it is liable to become stuck and held off the seat when it gets hot and expands. Make a center punch mark C, on the edge of the valve chest directly over the valve stem, and placing one leg of a tram or pair of dividers in the mark, with the other leg describe a mark on the top of the valve as at D, thus marking the valve in its central position.

Now with the rocker arm perpendicular, the eccentric rod having been previously adjusted, connect the valve rod to the rocker, and turn the eccentric to the limit of its throw in one direction, and measure the distance the valve has traveled from its central position. Then turn the eccentric around to its extreme throw in the other direction, and if the valve travels the same distance from its central position in the opposite direction the lengths of the rods are correct, but if not correct the necessary change can usually be made by shifting the nuts on the valve stem, or if the valve is secured to the stem by a yoke the change can be made in the rod.

Having succeeded in getting the correct travel for the valve, the next step is to set the eccentric. With the engine on the dead center, turn the eccentric around on the shaft in the direction in which the

engine is to run, so as to take up all the play in the valve stem and other moving parts, and with the tram or dividers watch the valve until it has moved away from its central position by the amount of its outside lap, plus the lead it is desired to give the valve. For instance, if the valve has one inch outside lap and the lead is to be ⅛ in., the valve should be moved away from its central position 1⅛ in., and also away from the end of the cylinder at which the piston is. The steam port for that end should now be open ⅛ in., and the eccentric should be ahead of the crank one-quarter turn plus the angular advance required for the outside lap and lead, or if as previously explained, the motion of the eccentric is reversed by a rocker arm the eccentric should be behind the crank by the same amount. Tighten the set screws holding the eccentric on to the shaft and turn the engine around until it is on the opposite center. Then if the lead is the same on each center the valve is set correctly. If the lead is not the same, move the valve on the stem toward the end having the most lead, a distance equal to one-half the difference between the two leads. If the lead as equalized is more than is desired, move the eccentric back on the shaft until the correct lead opening is secured, then tighten the set screws permanently, and with a sharp cold chisel make a plain mark on the shaft and opposite to this another mark on the eccentric. This will save considerable trouble in case the eccentric should slip or be accidentally moved from its true position at any time.

Although the common D slide valve as applied to stationary engines usually has its point of cut off fixed, yet there are many types of variable automatic cut off engines with single slide valves of various pat-

terns, such as box valves in which the steam passes through the valve, piston valves in which the steam either passes through or around the ends of the valve, so-called gridiron valves and various other types. Such valves are generally applied to high speed engines and are actuated by eccentrics which are under the control of shaft governors which vary the position of the eccentric with relation to the crank according to the load that is on the engine, thus regulating the point of cut off so as to maintain a constant speed, while the throttle is kept wide open. While the details of setting all the various styles of valves, including the corliss or four valve type, differ considerably from those required in setting the D valve, yet the same principles govern the operation, no matter what kind of a valve is to be adjusted

In all types of reciprocating engines the same factors affecting the distribution of the steam are present, viz., the outside or steam lap affecting admission and cut off, and the inside or exhaust lap affecting release and compression. While the D valve (and other types of single valves) combines these four principal factors within itself (that is, two steam laps and two exhaust laps), it should be noted that in the four valve type of engine the same factors are distributed among four valves, each valve performing its own particular function in controlling the distribution of the steam for the end of the cylinder to which it is attached. Also each valve may be adjusted to a certain degree independently of the others, and this fact goes far towards explaining why engines of this type, with the disengaging valve gear, are so much more economical in the use of steam than are those with the ordinary fixed cut off. Thus, for instance, the steam valves of

a corliss engine may be adjusted to cut off the steam at any point, from the very beginning up to one-half of the stroke, without in the least affecting the release or compression because these events are controlled by the exhaust valves.

As the corliss engine is a prominent and familiar type of the four valve detaching cut off engine, and embodies the main features of nearly all engines belonging to that class, it will be used to illustrate the method of setting the valves on a four valve engine.

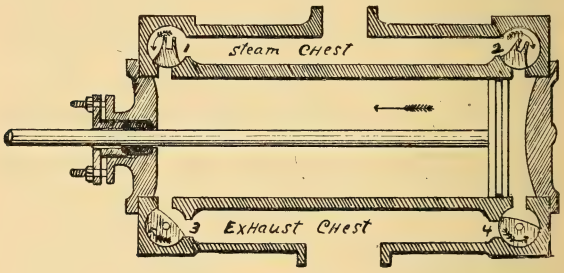


FIGURE 34.

Fig. 34 is a sectional view of the cylinder, steam and exhaust chests, and the valve chambers of a corliss engine. 1 and 2 are the steam valves and 3 and 4 the exhaust valves. The valves work in cylindrical chambers accurately bored out, the face of the valve being turned off to fit steam tight. They are what is termed rotative valves, that is, they receive a semi-rotary motion from the wrist plate, which in turn is actuated by the eccentric.

In some of the modern improved makes of four valve engines there are two eccentrics, one for the

steam and the other for the exhaust valves. This arrangement permits of still greater latitude in adjustments for the economical use of steam.

In Fig. 34 the piston is shown as just ready to begin the stroke towards the left. Admission is taking place at valve 2 and release at valve 3, valves 1 and 4 being closed. The arrows show the direction in which the valves move. Motion is transmitted from the wrist plate to the valves by means of short connecting rods and cranks attached to the valve stems. These rods

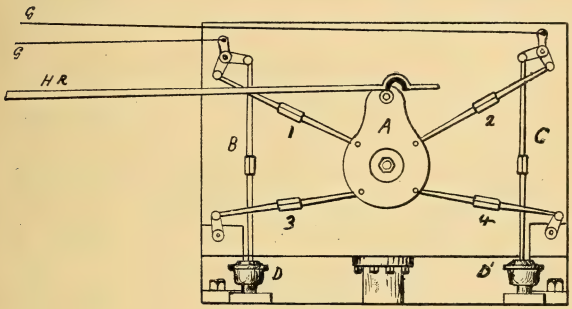


FIGURE 35.

are, or at least should be, fitted with right and left hand threads or turn buckles for the purpose of lengthening or shortening the rods while setting the valves.

The valve gear of a corliss engine with a single eccentric is shown in Fig. 35. The connections of the exhaust valves with the wrist plate are positive, and the travel of these valves is fixed, being a constant quantity, but the connections of the steam valves with the wrist plate are detachable, being under the control of the governor. Various designs of releasing mechan-

ism are in use by different builders, but the same general principles govern the operation of all, viz., that the valve is quickly opened at the commencement of the stroke when the wrist plate has its fastest motion, and that the governor trips the releasing meehanism at that point in the stroke at which it is desired that cut off should take place, and that the valve is then quickly closed by means of a vacuum dash pot or, as in some types of engines, by a spring. Connection is made between the wrist plate and rocker arm by means of the hook rod, so-called because it hooks over the wrist plate pin, and can easily be disconnected in case it is desired to work the valves by hand, as in warming up the engine preparatory to starting up.

Referring to Fig. 35, A is the wrist plate, B and C are the dash pot rods, D, D′ the dash pots and H R the hook rod. G and G′ represent the governor rods, and the figures 1, 2, 3 and 4 indicate the valve rods with turn buckles for changing their lengths.

As in setting the slide valve, the first requisite in setting corliss valves is to put the engine on the center, the method of doing which has been fully described. Next adjust the length of the hook rod, if it is adjustable, if not, then the eccentric rod so that the wrist plate will vibrate equal distances each way from its central position which is marked on top of the hub. (See Fig. 36.) It will be noticed that there are four marks, A, B, C and D. Marks A and B are on the hub of the wrist plate and the stationary flange against which it turns, and when they are in line, indicate that the wrist plate is central. Marks C and D are on the stationary flange at equal distances each way from B, and when the engine is running mark A should travel to the right until it is in line with D and

to the left until in line with C, or it may happen that A will travel past C and D or perhaps not quite to them, but which ever it does, it should stop at equal distances from them. This adjustment should be carefully made before setting the valves, because if any

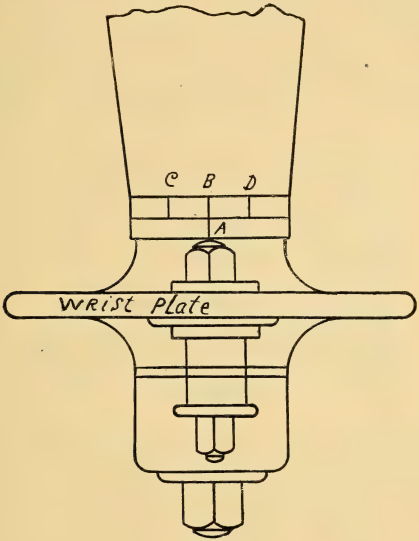


FIGURE 36.

change is made in the lengths of the eccentric rod or hook rod after the valves are once set it will seriously affect the action of all the valves.

The method of adjusting the rocker arm so that it will vibrate correctly has been already described and it is very desirable that its travel should be equidistant

in either direction from a vertical position, but if it is found that the hook rod is non-adjustable as to length and that the wrist plate still vibrates too far in one direction, then the adjustment must be made on the length of the eccentric rod, which can be screwed into or out of the strap. The vibration of the wrist plate should then be tested by turning the eccentric around on the shaft in the direction the engine is to run. When this is found to be correct the next step is to remove the back bonnets from the valve chambers. Fig. 37 represents one of the steam valves and Fig. 38

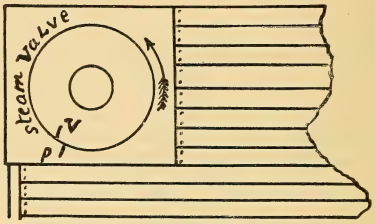


FIGURE 37.

one of the exhaust valves, each with back bonnet removed, showing the ends of the valves.

The working edges of the valves, as well as the ports of a corliss engine, cannot be seen when the valves are in place, owing to the fact that the circular ends of the valves fill the spaces at the ends of the valve chambers, but certain marks will be found on the ends of the valves, and corresponding marks on the faces of the chambers which serve as a guide in setting the valves. Referring to Fig. 37, mark V on the end of the valve is in line with the edge of the valve, and P indicates the edge of the port. The same let-

ters apply to Fig. 38. Having removed the bonnets and found the marks, temporarily secure the wrist plate in its central position by tightening one of the set screws on the eccentric. Then connect the valve rods, adjusting their lengths so that the steam valves will have from $\frac{1}{4}$ to $\frac{9}{16}$ in. lap, as in Fig. 37, and the exhaust valves from $\frac{1}{32}$ to $\frac{3}{16}$ in. opening, as in Fig. 38. These figures vary according to the size of the engine, the smaller figures being for small size engines and the larger figures apply to large sizes.

In adjusting the steam valves be sure and note the

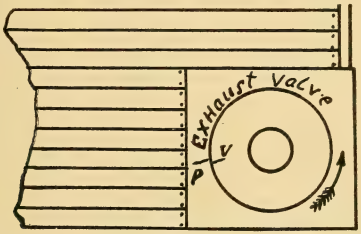


FIGURE 38.

direction in which they turn to open. In most corliss engines the arm of the crank to which the valve rod is connected extends downwards from the valve stem, as in Fig. 35. This will cause the valve to move towards the wrist plate in opening. After the valve rods have been properly adjusted as to length, place the engine on either center by the method previously explained and move the eccentric around on the shaft in the direction in which the engine is to run until it is far enough ahead of the crank to allow the steam valve the proper amount of lead opening, which will vary according to the size of the engine. Table 7

gives the lap and lead for various sizes of corliss engines from 12 to 42 in. bore. Having tightened the

TABLE 7.

Size of Engine.	Lap of Steam Valve.	Lead Opening of Steam Valve.	Lead Opening of Exhaust Valve.
12 inches	$\frac{1}{4}$ inch	$\frac{1}{32}$ inch	$\frac{1}{32}$ inch
14 "	$\frac{5}{16}$ "	$\frac{1}{32}$ "	$\frac{1}{32}$ "
16 "	$\frac{5}{16}$ "	$\frac{1}{16}$ "	$\frac{1}{32}$ "
18 "	$\frac{3}{8}$ "	$\frac{1}{16}$ "	$\frac{1}{16}$ "
20 "	$\frac{3}{8}$ "	$\frac{1}{16}$ "	$\frac{1}{16}$ "
22 "	$\frac{3}{8}$ "	$\frac{1}{16}$ "	$\frac{1}{16}$ "
24 "	$\frac{7}{16}$ "	$\frac{3}{32}$ "	$\frac{3}{32}$ "
26 "	$\frac{7}{16}$ "	$\frac{3}{32}$ "	$\frac{3}{32}$ "
28 "	$\frac{7}{16}$ "	$\frac{3}{32}$ "	$\frac{3}{32}$ "
30 "	$\frac{1}{2}$ "	$\frac{3}{32}$ "	$\frac{1}{8}$ "
32 "	$\frac{1}{2}$ "	$\frac{3}{32}$ "	$\frac{1}{8}$ "
34 "	$\frac{1}{2}$ "	$\frac{1}{8}$ "	$\frac{1}{8}$ "
36 "	$\frac{1}{2}$ "	$\frac{1}{8}$ "	$\frac{1}{8}$ "
38 "	$\frac{9}{16}$ "	$\frac{1}{8}$ "	$\frac{3}{16}$ "
40 "	$\frac{9}{16}$ "	$\frac{1}{8}$ "	$\frac{3}{16}$ "
42 "	$\frac{9}{16}$ "	$\frac{1}{8}$ "	$\frac{3}{16}$ "

eccentric set screws, turn the engine around to the opposite center and note whether the lead is the same on each end. If there is a difference it can generally be equalized by slightly altering the length of one of the valve rods. The valves should also be adjusted by means of the indicator at the first opportunity, as that is the only absolutely correct method.

The next point to receive attention is the adjustment of the lengths of the horizontal rods extending from the governor to the releasing mechanism, so that the steam valves will cut off at equal points in the stroke. This is done by raising the hook rod clear of the wrist plate pin, and with the bar provided for the purpose move the wrist plate to either one of its extreme positions as shown by the marks on the hub (see Fig. 36)

and holding it in this position adjust the length of the governor rod for the steam valve (which will then be wide open) so that the boss or roller which trips the releasing mechanism is just in contact, or within $\frac{1}{32}$ in. of it. Then move the wrist plate to the other extreme of its travel and adjust the length of the other rod in the same manner. To prove the accuracy of the adjustment, raise the governor balls to their medium position, or about where they would be when the engine is running at its normal speed and block them there. Then having again connected the hook rod to the wrist plate, turn the engine around in the direction in which it is to run, and when the valve is released, measure the distance upon the guide that the crosshead has traveled from the end of the stroke. Now continue to turn the engine in the same direction until the other valve is released, and measure the distance that the crosshead has traveled from the opposite end of the stroke, and if the cut off is equalized these two distances will be the same. If there is a difference, lengthen one rod and shorten the other until the point of cut off is the same for both ends.

The lengths of the dash pot rods should also be adjusted so that when the plunger is at the bottom of the dash pot the valve lever will engage the hook.

After all adjustments have been made tighten the lock nuts on all the rods.

Questions

1. What important features in the operation of an engine are dependent upon a correct adjustment of the valves?

2. How many different types of valves are there in general use?

3. What are the basic principles governing the adjustment of the valves of an engine?

4. Name two important functions of a valve.

5. What is the effect of increasing the outside lap?

6. What is the result of increasing the inside lap?

7. What advantage has an engine of the four valve type over one with but a single valve?

8. Suppose a valve had neither lap nor lead, what would be the position of the eccentric in relation to the crank?

9. What is meant by the term "angular advance," and why is it necessary?

10. What is the first function of the valve at the commencement of the stroke?

11. What is the second function?

12. What is the travel of a slide valve equivalent to?

13. What is the third function of the valve?

14. What is the fourth function?

15. What will be the effect if a valve has no inside lap?

16. How can the action of a slide valve be graphically illustrated?

17. Name the two most commonly used valve diagrams.

18. What is meant by the expression, "radius of eccentricity"? (See Chapter VIII.)

19. Why must a valve have outside lap?

20. What is the object in giving a valve inside lap?

21. What is the result of decreasing the angular advance?

22. What will be the result if the travel of the valve is decreased?

23. What three changes must be made in order to

cause an earlier cut off in an engine that has a fixed cut off?

24. What is the first step in the operation of valve setting?

25. When is an engine on the dead center?

26. What precautions should be observed in turning an engine to place it on the center?

27. Why is this necessary?

28. Describe briefly the process of placing an engine on the dead center.

29. What is the next move in the routine of valve setting?

30. What should be done with the valve before connecting it to the valve rod?

31. How may the outside lap be ascertained?

32. How is the amount of inside lap found?

33. Should the valve be rigidly secured to the stem?

34. Describe the proper method of adjusting the length of the rod in order that the valve may travel correctly.

35. How is the correct position of the eccentric on the shaft ascertained?

36. If the lead is not the same at each end of the stroke, how may it be equalized?

37. If there is more lead than is desired, how may it be decreased?

38. What is the function of a shaft governor in relation to the eccentric?

39. Why is the four valve type of engine more economical in the use of steam than the single valve type with fixed cut off?

40. How should the wrist plate be adjusted?

41. If the wrist plate does not vibrate correctly what will be the result?

42. How should the rods connecting the governor with the releasing mechanism be adjusted?

43. How may this adjustment be tested?

44. How should the dash pot rods be adjusted as to length?

CHAPTER VII

THE INDICATOR

The indicator—Its invention and improvement—Principles governing its operation—Diagrams from condensing and non-condensing engines—Sizes of springs to be used for various pressure—Reducing mechanism—The reducing wheel—Different forms of pendulum reducing motion—Brumbo pulley—The pantograph—Attaching the indicator—Parts of the cylinder to which indicator pipes should not be connected—Care of the instrument—Cleaning, oiling, etc.—Directions for taking diagrams.

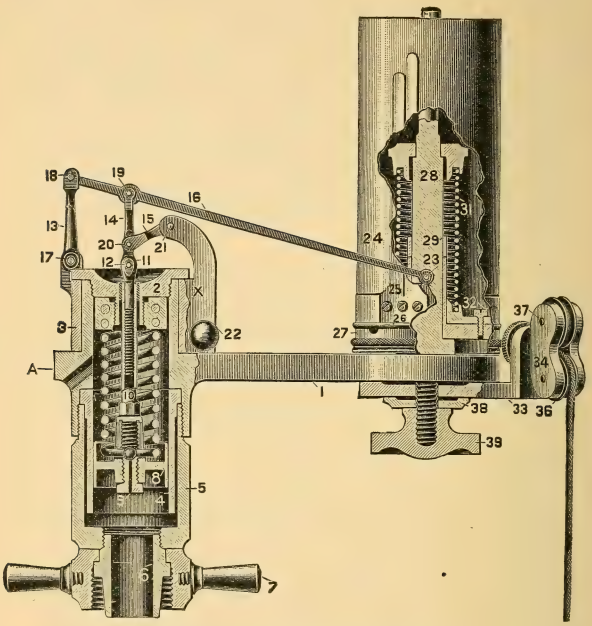
The Indicator. One of the greatest aids to the economical operation of the steam engine is the indicator, and it is the privilege of every engineer to have at least an elementary, if not a thorough knowledge of its principles and working. The time devoted to the study of the indicator, and in its application to the engine, is time well spent, and in the end will well repay the student of steam engineering.

Inventor. The indicator was invented and first applied to the steam engine by James Watt, whose restless genius was not satisfied with a mere outside view of his engine as it was running, but he desired to know more about the action of the steam in the cylinder, its pressure at different portions of the stroke, the laws governing its expansion after being cut off, etc. Watt's indicator, although crude in its design and construction, contained embodied within it all of the principles of the modern instrument.

Principles. These principles are:

First. The pressure of the steam in the engine

cylinder throughout an entire revolution, against a small piston in the cylinder of the indicator, which in turn is controlled or resisted in its movement by a



SECTIONAL VIEW CROSBY INDICATOR.

spring of known tension, so as to confine the stroke of the indicator piston within a certain small limit.

Second. The stroke of the indicator piston is communicated by a multiplying mechanism of levers and parallel motion to a pencil moving in a straight line. The distance through which the pencil moves being

governed by the pressure in the engine cylinder and the tension of the spring.

Third. By the intervention of a reducing mechanism and a strong cord, the motion of the piston of the engine throughout an entire revolution is communicated to a small drum attached to and forming a part of the indicator. The movement of the drum is rotative and in a direction at right angles to the movement of the pencil. The forward stroke of the engine piston causes the drum to rotate through part of a revolution and at the same time a clock spring connected within the drum is wound up. On the return stroke the motion of the drum is reversed and the tension of the spring returns the drum to its original position and also keeps the cord taut.

CROSBY INDICATOR SPRING.

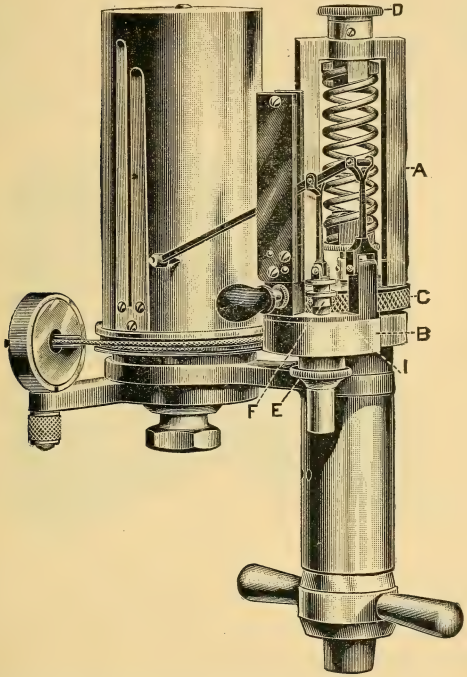
To the outside of the drum a piece of blank paper of suitable size is attached and held in place by two clips. Upon this paper the pencil in its motion up and down traces a complete diagram of the pressures and other interesting events transpiring within the engine cylinder during the revolution of the engine. In fact the diagram traced upon the paper is the compound result of two concurrent movements. First, that of the pencil caused by the pressure of the steam against the indicator piston; second, that of the paper drum caused by, and coincident with, the motion of the engine piston. The upper end of the indicator cylinder is always open to the atmosphere, the steam acting only upon the underside of the small piston, and when the cock connecting the cylinders of the engine and

indicator is closed, both ends of the indicator cylinder are open to atmospheric pressure, and the pencil then stands at its neutral position. If now the pencil is held against the paper and the drum rotated either by hand or by connecting it with the cord, a horizontal line will be traced. This line is called the atmospheric line, meaning the line of atmospheric pressure, and it is a very important factor in the study of the diagram.

If the engine is a non-condensing engine the pencil in tracing the diagram will, or at least, should not fall below the atmospheric line at any point, but will on the return stroke trace a line called the line of back pressure at a distance more or less above the atmospheric line and very nearly parallel with it. If the engine is a condensing engine the pencil will drop below the atmospheric line while tracing the line of back pressure on the diagram, and the distance this line is below the atmospheric line will depend upon the number of inches of vacuum in the condenser.

As before stated, the length of stroke of the indicator piston and the pencil movement as well is controlled by a spiral steel spring which acts in resistance to the pressure of the steam. These springs are made of different tensions in order to be suitable to different steam pressures and speeds, and are numbered 20, 40, 60, etc., the number meaning that a pressure per square inch in the engine cylinder corresponding to the number on the spring will cause a vertical movement of the pencil through a distance of one inch. Thus, if a number 20 spring is used and the pressure in the cylinder at the commencement of the stroke is 20 lbs. per square inch, the pencil will be raised one inch, or if the pressure is 30 lbs., the pencil will travel 1½ in., and if there is a vacuum of 20 in. in the condenser,

the pencil will drop ½ in. below the atmospheric line for the reason that 20 in. of vacuum corresponds to a



IMPROVED TABOR INDICATOR WITH OUTSIDE CONNECTED SPRING. ASHCROFT MFG. CO., N. Y.

pressure of about 10 lbs. less than atmospheric pressure or an absolute pressure of about 4 lbs. If a 60 spring is used a pressure of 60 lbs. in the engine cylinder will

be required to raise the pencil one inch, or 90 lbs. to raise it 1½ in.

The Ashcroft Manufacturing Co. of New York, makers of the well known Tabor indicator, have recently introduced a new feature in indicator work by connecting the spring on top of the cylinder and in plain view of the operator. This arrangement removes the spring from the influence of direct contact with the

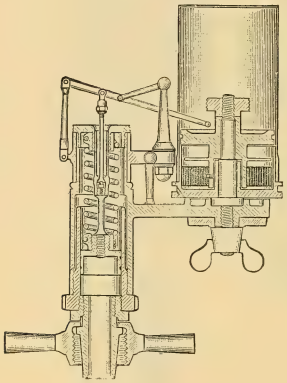


FIGURE 39.

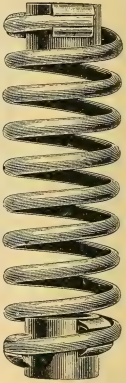


FIGURE 40.

steam, and it is subject only to the temperature of the surrounding atmosphere. It is claimed that as a result of this the accuracy of the spring is insured and that no allowance need to be made in its manufacture for expansion caused by the high temperature to which it is subject when located within the cylinder. Another good feature of this design is, that the spring can be easily removed without disconnecting any one part of the instrument in case it is desired to change springs.

A cut of the improved instrument is herewith presented.

Fig. 39 is a sectional view of the American Thompson improved indicator. Fig. 40 shows the spring. Fig. 41 is a three way cock for attaching the indicator to the cylinder.

Reducing Mechanism. Probably the only practically universal mechanism for reducing the motion of the crosshead is the reducing wheel, a device in which, by

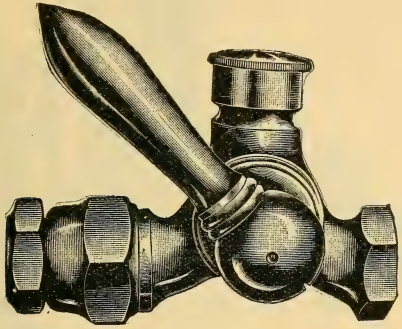


FIGURE 41.

the employment of gears and pulleys of different diameters, the motion is reduced to within the compass of the drum, and the device is applicable to almost any make of engine, whether of high or low speed. Some makers of indicators attach the reducing wheel directly to the indicator, thus producing a neat and very convenient arrangement. Fig. 42 shows the indicator complete with reducing wheel attached.

One of the most accurate and easily applied devices for reducing the motion of the piston is the wooden

pendulum in its various forms. (See Figs. 43, 44 and 45.) It consists of a flat strip of pine or other light wood of a length not less than one and a half times the stroke of the engine, and if made longer it will be better. It should be from ¾ to ⅞ in. thick and have an average width of about 4 in. If the engine to be

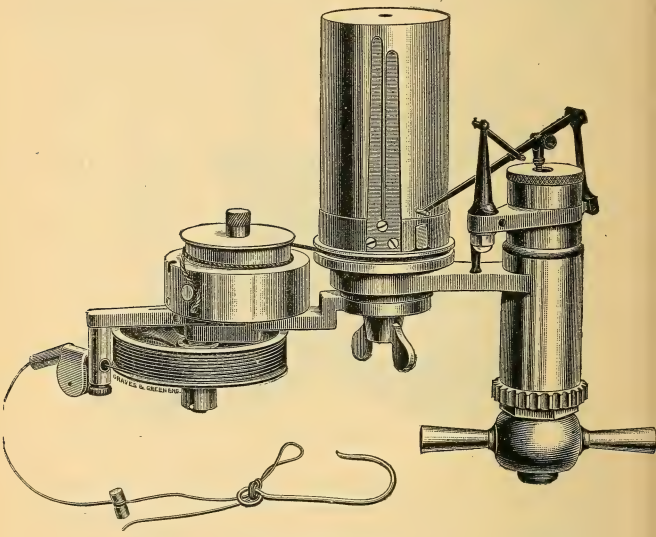


FIGURE 42.

indicated is horizontal the bar or pendulum is to be pivoted at a fixed point directly above and in line with the side of the crosshead, as that is generally the most convenient point of attachment. The pivot can be fixed to a permanent standard bolted to the frame of the engine (Fig. 46), or it may be secured to the ceil-

ing of the room or even to a post fastened to the floor. If the engine is vertical the bar can be pivoted to the wall of the room or a strong post firmly secured to the floor. The connection with the crosshead is best accomplished by means of a short bar or link. A convenient length for this bar is one-half the stroke of the engine. To locate the correct point for the pivot,

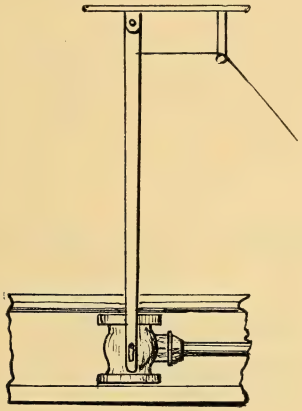


FIGURE 43.

assuming the length of the short bar to be one-half the length of the stroke, proceed as follows:

Place the engine on the center with the crosshead at the end of the stroke towards the crank. Then having previously bored a hole for the pivot in one end of the pendulum bar and in the other end a hole for connecting with the link, suspend the pendulum by a temporary pin, as a large wood screw, directly above and in

line with the stud or bolt hole which has previously been tapped into the crosshead at any convenient point. The pendulum should be temporarily suspended at such a height that when it hangs perpendicular the hole in its lower end will line up accurately with the hole or stud in the crosshead. Now swing the pendulum in either direction a distance equal to the length of the link (one-half the stroke of the

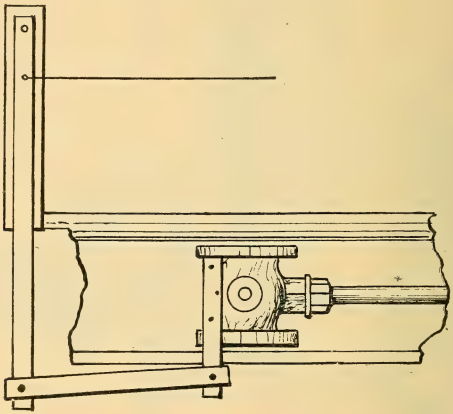


FIGURE 44.

engine) from the crosshead connection and note the distance that the bottom hole is above a straight edge laid horizontal and in line with the center of the stud in the crosshead. This will give the total vibration of the free end of the link from a line parallel with the line of the engine and the permanent location of the pivot should be one-half of this distance below the temporary point of suspension. This will allow the link

to vibrate equally above and below the center of its connection with the crosshead. Fig. 47 shows a complete connection of this character.

Sometimes the end is slotted and thus directly connected to the stud in the crosshead, dispensing with the link. In this case it is necessary to locate the pivot at a point perpendicular to the center of travel of the stud in the crosshead. (See Fig. 43.) The link

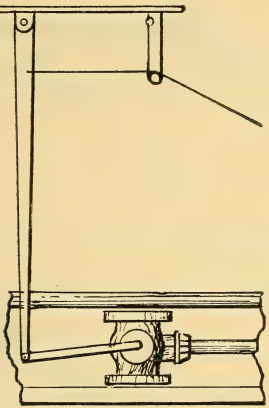


FIGURE 45.

connection is to be preferred, however. The cord can be attached to the pendulum at a point near the pivot which will give the desired length of diagram. This point can be determined by multiplying the length of the pendulum by the desired length of diagram and dividing the product by the stroke. For convenience these terms should be expressed in inches. Thus, assume stroke of engine to be 48 in., length of pendu-

lum 1½ times length of stroke = 72 in. Desired length of diagram 3 in. Then $72 \times 3 \div 48 = 4.5$ in., which is

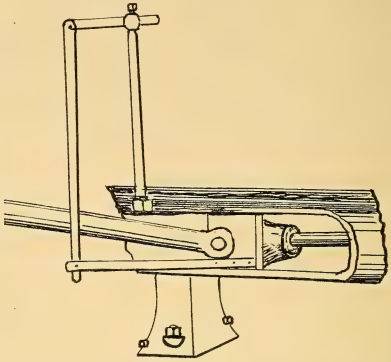


FIGURE 46.

the distance from center of pivot to point of connection for the cord. This can be either a small hole

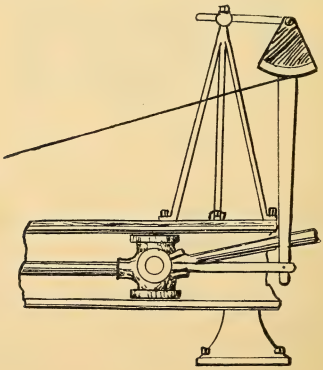


FIGURE 47.

bored through the pendulum or a wood screw to which the cord can be attached. From this point the cord should be led over a guide pulley located at such height that when the pendulum is vertical the cord will leave it at right angles. After leaving the guide pulley the cord can be carried at any angle desired.

The Brumbo Pulley. Another method of connecting the cord to the pendulum is to run the cord over a grooved segment, called a Brumbo pulley, connected

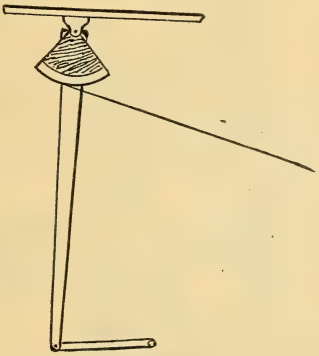


FIGURE 48.

with the pivoted end of the pendulum (Fig. 48), but with this arrangement, owing to the curved travel of the pendulum, there is greater liability to distortion of the diagram than in the first method. In case it is desired to use the Brumbo pulley, the radius of the segment can be found by the same process as that used for finding the point for connecting the cord directly to the pendulum.

One of the neatest and most easily applied devices

for reducing the motion of the crosshead is the pantograph. (See Fig. 49.) No dimensions are essential except that it shall be made reasonably strong of some light, tough variety of wood, and that the pins and holes be nicely fitted to each other so that while the movement may be free there shall at the same time not be too much lost motion. The pantograph should be of such capacity that it will just close up nicely when the engine is at mid stroke and open out nicely when at its extreme travel. The two ends, C and D,

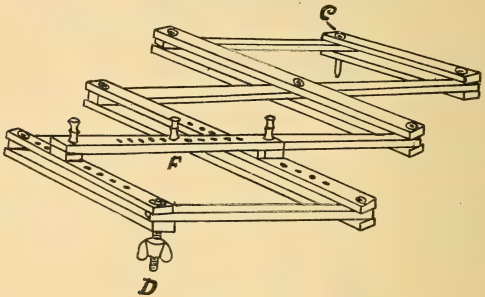
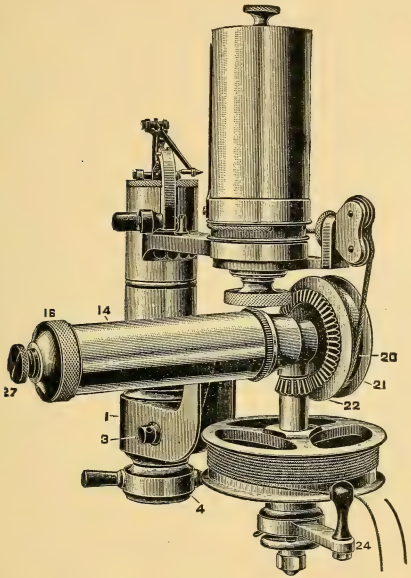


FIGURE 49.

are each to be fitted with a pin extending through far enough so that pin C can be hooked into a hole or socket on the crosshead, while pin D rests in a socket in the top of a post secured to the floor at a point opposite the center of travel of the crosshead and of such height as will allow the pantograph to lie in a horizontal position. Also the distance of the post from the guides must be adjusted so as to allow the device to close up at mid stroke and open out at full stroke without any straining of the parts. The point F of connection for the cord will always have a motion

parallel with, and simultaneous with, that of the cross-head; the pin to which the cord is attached can be set in any one of the holes that will give the desired length for the diagram. The motion given by this device is accurate, although it may become necessary



CROSBY REDUCING WHEEL.

in some cases, especially with long stroke engines, to introduce a guide pulley to carry the cord from the pantograph.

Attaching the Indicator. The cylinders of most engines at the present time are drilled and tapped for

indicator connections before they leave the shop, which is eminently proper, as no engine builder, or purchaser either, should be satisfied with the performance of a new engine until after it has been accurately tested and adjusted with the indicator.

The main requirements in these connections are that the holes shall not be drilled near the bottom of the cylinder where water is likely to find its way into the pipes, neither should they be in a location where the inrush of steam from the ports will strike them directly, nor where the edge of the piston is liable to partly cover them when at its extreme travel. An engineer before he undertakes to indicate an engine should satisfy himself that all these requirements are fulfilled. Otherwise he is not likely to obtain a true diagram. The cock supplied with the indicator is threaded for one-half inch pipe and unless the engine has a very long stroke it is the practice to bring the two end connections together at the side or top of the cylinder and at or near the middle of its length, where they can be connected to a three way cock. The pipe connections should be as short and as free from elbows as possible in order that the steam may strike the indicator piston as nearly as possible at the same moment that it acts upon the engine piston.

The work of taking diagrams is very much simplified by having both ends of the cylinder connected to one common tee or a three way cock as above described, but for long stroke engines there should be two indicators, one for each end and the diagrams should be taken simultaneously if it is desired to adjust the valves by the indicator. In this case an assistant would be required to manipulate one of the instruments.

The pipes should always be thoroughly blown out by allowing the steam to blow through the open cock during several revolutions of the engine, before connecting the indicator. If this is not done there is a moral certainty that grit and dirt will get into the cylinder of the indicator, where the pressure of the least atom of grit will cause the delicate instrument to work badly.

Selecting a Spring. The proper number of spring to use depends upon the boiler pressure in the case of an automatic cut off engine, but for an engine with a fixed cut off and throttling governor the number of the spring to be selected will depend upon the initial pressure in the cylinder. A convenient rule is to select a spring numbered one-half as high as the pressure; for instance, if the boiler pressure is 80 lbs., use a No. 40 spring, which will give a diagram 2 in. in height.

Care of the Instrument. The indicator should be cleaned and oiled both before and after using. The best material for wiping it is a clean piece of old soft muslin of fine texture, as there is not so much liability of lint sticking to or getting into the small joints. Use good clock oil for the joints and springs, and before taking diagrams it is a good practice to rub a small portion of cylinder oil on the piston and the inside of the cylinder, but when about to put the instrument away these should be oiled with clock oil also. None but the best cord should be used for connecting the paper drum with the reducing motion, as a cord that is liable to stretch will cause trouble. Suitable cord and also blank diagrams can generally be secured from firms manufacturing and selling indicators. After the indicator has been screwed on to the cock connecting with the pipe, the cord must be adjusted to the proper

length before hooking it on to the drum. This must be done while the engine is running, by taking hold of the loop on the cord connected with the reducing motion with one hand, and with the other hand grasp the hook on the short cord attached to the drum, then by holding the two ends near each other during a revolution or two it will be seen whether the long cord needs to be shortened or lengthened.

The length of the diagram is determined by the point of connection of the cord to the pendulum as has been heretofore explained. Care should be exercised in placing the paper on the drum to see that it is stretched tight and firmly held by the clips. The pencil point having been first sharpened by rubbing it on a piece of fine emery cloth or sand paper should be adjusted by means of the pencil stop with which all indicators should be provided, so that it will have just sufficient bearing against the paper to make a fine, plain mark. If the pencil bears too hard on the paper it will cause unnecessary friction and the diagram will be distorted. The best method of ascertaining this fact and also whether the travel of the drum is equally divided between the stops, is to place a blank diagram on the drum, connect the cord and while the engine makes a revolution hold the pencil against the paper. Then unhook the cord, remove the paper and if the travel of the drum is not divided correctly it can be changed.

Having thus arranged all the preliminary details, place a fresh blank on the drum, being careful to keep the pencil out of contact with it, connect the cord, open the cock admitting steam to the indicator and after the pencil has made a few strokes to allow the cylinder to become warmed up, then gently swing it

around to the paper drum and hold it there while the engine makes a complete revolution. Then move the pencil clear of the paper, close the cock and unhook the cord. Now trace the atmospheric line by holding the pencil against the paper while the drum is revolved by hand. This method of tracing the atmospheric line is preferable to that of tracing it immediately after closing the cock and while the drum is still being moved by the engine, for the reason that there is not so much liability of getting the atmospheric line too high owing to the presence of a slight pressure of steam remaining under the indicator piston for a second or two just after closing the cock; also the line drawn by hand will be longer than one drawn while the drum is moved by the motion of the engine and will therefore be more readily distinguished from the line of back pressure.

Having secured a truthful diagram, it now remains to take as many as are desired, and if the object is to set the valves of the engine, the diagrams from each end of the cylinder should follow each other as quickly as possible in order that the conditions of load and steam pressure may be the same. When the indicator is connected so that diagrams can be taken from both ends without changing it, the above conditions can generally be realized. But if diagrams can only be taken from one end at a time, the only way to arrive at correct conclusions in relation to the adjustment of the valves will be to see that the boiler pressure is practically the same at the time of taking diagrams from either end and that the position of the governor is also the same, assuming that the load on the engine is practically constant. This applies of course to an automatic cut off.

As soon as the diagrams are taken the following data should be noted upon them: The end of the cylinder, whether head or crank; boiler pressure; and time when taken. Other data can be added afterwards. If the engine is an automatic cut off of the corliss type and the point of cut off on one end does not coincide with the other, the difference can generally be adjusted while the engine is running by changing the length of the rods extending from the governor to the tripping device. These rods are, or should be, fitted with right and left threads on the ends for this purpose. Any changes in the valves, such as giving them more lead, compression, etc., and which necessitates changing the length of the reach rods connecting them with the wrist plate, will have to be made while the engine is stopped, although with slow speed engines and the exercise of caution it is possible to make alterations in these rods while the engine is running.

Questions

1. What instrument is a necessary part of an engineers outfit?
2. Who invented the indicator?
3. Name the principles governing the action of the indicator.
4. What will a truthful diagram from a steam cylinder show?
5. Does the steam act upon both sides of the indicator piston?
6. What does the atmospheric line show?
7. Is this line important in the study of the diagram?
8. Where should the line of back pressure appear in a diagram from a non-condensing engine?

9. Where will the line of back pressure appear on a diagram from a condensing engine?

10. What controls the length of stroke of the indicator piston?

11. What does the number on the spring mean?

12. What is one of the most convenient appliances for reducing the motion of the crosshead within the compass of the drum?

13. What other appliances besides the reducing wheel may be employed for this purpose?

14. What is a Brumbo pulley?

15. What are the main requirements in indicator connections?

16. What should be done with the pipes before attaching the indicator?

17. Upon what does the selection of the scale of spring depend?

18. What is a convenient rule to be observed in the selection of a spring?

19. What is the best method of tracing the atmospheric line?

20. What data should be noted on the diagram as soon as it is taken?

CHAPTER VIII

DEFINITIONS AND TABLES

Definition of words, terms and phrases—Table of hyperbolic logarithms—Table of areas and circumferences of circles.

In order to facilitate the study and analysis of indicator diagrams, the following definitions of technical terms, some of which have already been explained in another part of this book, are here given.

Absolute pressure. Pressure reckoned from a perfect vacuum. It equals the boiler pressure plus the atmospheric pressure.

Boiler pressure or gauge pressure. Pressure above the atmospheric pressure as shown by the steam gauge.

Initial pressure. Pressure in the cylinder at the beginning of the stroke.

Terminal pressure (*T. P.*). The pressure that would exist in the cylinder at the end of the stroke provided the exhaust valve did not open until the stroke was entirely completed. It may be graphically illustrated on the diagram by extending the expansion curve by hand to the end of the stroke. It is found theoretically by dividing the pressure at point of cut off by the ratio of expansion. Thus, absolute pressure at cut off = 100 lbs., ratio of expansion = 5; then 100 ÷ 5 = 20 lbs., absolute terminal pressure.

Mean effective pressure (*M. E. P.*). The average pressure acting upon the piston throughout the stroke minus the back pressure.

Back pressure. Pressure which tends to retard the forward stroke of the piston. Indicated on the diagram from a non-condensing engine by the height of

the back pressure line above the atmospheric line. In a condensing engine the degree of back pressure is shown by the height of the back pressure line above an imaginary line representing the pressure in the condenser corresponding to the degree of vacuum in inches, as shown by the vacuum gauge.

Total or absolute back pressure, in either a condensing or non-condensing engine, is that indicated on the diagram by the height of the line of back pressure above the line of perfect vacuum.

Ratio of expansion. The proportion that the volume of steam in the cylinder at point of release bears to the volume at cut off. Thus, if the point of cut off is at one-fifth of the stroke, and release does not take place until the end of the stroke, the ratio of expansion, or in other words, the number of expansions, is 5. When the T. P. is known the ratio of expansion may be found by dividing the initial pressure by the T. P.

Wire drawing. When through insufficiency of valve opening, contracted ports, or throttling governor, the steam is prevented from following up the piston at full initial pressure until the point of cut off is reached, it is said to be wire drawn. It is indicated on the diagram by a gradual inclination downwards of the steam line from the admission line to the point of cut off. Too small a steam pipe from boiler to engine will also cause wire drawing and fall of pressure.

Condenser pressure may be defined as the pressure existing in the condenser of an engine, caused by the lack of a perfect vacuum. As, for instance, with a vacuum of 25 in. there will still remain the pressure due to the 5 in. which is lacking. This will be about 2.5 lbs.

Vacuum. That condition existing within a closed vessel from which all matter, including air, has been expelled. It is measured by inches in a column of mercury contained within a glass tube a little over 30 in. in height, having its lower end open and immersed in a small open vessel filled with mercury. The upper end of the glass tube is connected with the vessel in which the vacuum is to be produced. When no vacuum exists the mercury will leave the tube and fill the lower vessel. When a vacuum is maintained in the condenser, or other vessel, the mercury will rise in the glass tube to a height corresponding to the degree of vacuum. If the mercury rises to the height of 30 in. it indicates a perfect vacuum, which means the absence of all pressure within the vessel, but this condition is never realized in practice; the nearest approach to it being about 28 in.

For purposes of convenience the mercurial vacuum gauge is not generally used, it having been replaced by the Bourdon spring gauge, although the mercury gauge is used for testing.

The vacuum in a condenser is generally maintained by an air pump, although it can be produced and maintained by the mere condensation of the steam as it enters the condenser by allowing a spray of cold water to strike it. The steam when it first enters the condenser drives out the air and the vessel is filled with steam which, when condensed, occupies about 1,600 times less space than it did before being condensed, hence a partial vacuum is produced.

While the vacuum in a condenser cannot be considered as power at all, yet it occupies the anomalous position of increasing, by its presence, the capacity of the engine for doing work. This is owing to the fact

that the atmospheric pressure or resistance which is always ahead of the piston in a non-condensing engine is, in the case of a condensing engine, removed to a degree corresponding to the height of the vacuum, thus making available just so much more of the pressure behind the piston. Thus, if the average steam pressure throughout the stroke is 30 lbs. and there is a vacuum of 26 in. maintained in the condenser, there will be 13 lbs. of resistance per square inch removed from in front of the piston, thus making available 30 + 13 = 43 lbs. pressure per square inch.

Absolute zero has been fixed by calculation at 461.2° below the zero of the Fahrenheit scale.

Piston displacement. The space or volume swept through by the piston in a single stroke. Found by multiplying the area of piston by length of stroke.

Piston clearance. The distance between the piston and cylinder head when the piston is at the end of the stroke.

Steam clearance, ordinarily termed clearance. The space between the piston at the end of the stroke and the valve face. It is reckoned in per cent. of the total piston displacement.

Horse power (*H. P.*). 33,000 pounds raised one foot high in one minute of time.

Indicated horse power (*I. H. P.*). The horse power as shown by the indicator diagram. It is found as follows:

Area of piston in square inches × M. E. P. × piston speed in feet ÷ 33,000.

Piston speed. The distance in feet traveled by the piston in one minute. It is the product of twice the length of stroke expressed in feet multiplied by the number of revolutions per minute.

R. P. M. Revolutions per minute.

Net horse power. I. H. P. minus the friction of the engine.

Compression. The action of the piston as it nears the end of the stroke, in reducing the volume and raising the pressure of the steam retained in the cylinder ahead of the piston by the closing of the exhaust valve.

Boyle's or Mariotte's law of expanding gases. "The pressure of a gas at a constant temperature varies inversely as the space it occupies." Thus, if a given volume of gas is confined at a pressure of 50 lbs. per square inch and it is allowed to expand to twice its volume, the pressure will fall to 25 lbs. per square inch.

Adiabatic curve. A curve representing the expansion of a gas which loses no heat while expanding. Sometimes called the curve of no transmission.

Isothermal curve. A curve representing the expansion of a gas having a constant temperature but partially influenced by moisture, causing a variation in pressure according to the degree of moisture or saturation. It is also called the theoretical expansion curve.

Expansion curve. The curve traced upon the diagram by the indicator pencil showing the actual expansion of the steam in the cylinder.

First law of thermodynamics. Heat and mechanical energy are mutually convertible.

Power. The rate of doing work, or the number of foot pounds exerted in a given time.

Unit of work. The foot pound, or the raising of one pound weight one foot high.

First law of motion. All bodies continue either in a state of rest or of uniform motion in a straight line,

except in so far as they may be compelled by impressed forces to change that state.

Work. Mechanical force or pressure cannot be considered as work unless it is exerted upon a body and causes that body to move through space. The product of the pressure multiplied by the distance passed through and the time thus occupied is work.

Momentum. Force possessed by bodies in motion, or the product of mass and density.

Dynamics. The science of moving powers or of matter in motion, or of the motion of bodies that mutually act upon each other.

Force. That which alters the motion of a body, or puts in motion a body that was at rest.

Maximum theoretical duty of steam is the product of the mechanical equivalent of heat, viz., 778 ft. lbs. multiplied by the total heat units in a pound of steam. Thus, in one pound of steam at 212° reckoned from 32° the total heat equals 1,146.6 heat units. Then $778 \times 1{,}146.6$ equals 892,054.8 ft. lbs. = maximum duty.

Steam efficiency may be expressed as follows: $\frac{\text{Heat converted into useful work}}{\text{Heat expended}}$ and maximum efficiency can only be attained by using steam at as high an initial pressure as is consistent with safety and at as large a ratio of expansion as possible. The percentage of efficiency of steam used at atmospheric pressure in a non-expansive engine is very low; as, for instance, the heat expended in the evaporation of one pound of water at 32° into steam at atmospheric pressure = 1,146.6 heat units, and the volume of steam so generated = 26.36 cu. ft.

One cubic foot of steam at 212° contains energy equal to $144 \times 14.7 = 2{,}116.8$ ft. lbs., and 26.36 cu.

ft. = 2,116.8 × 26.36 = 55,798.84 ft. lbs., which divided by the mechanical equivalent of heat, viz., 778 ft. lbs. = 71.72 heat units, available for useful work. The per cent. of efficiency therefore is $\frac{71.72 \times 100}{1,146.6} = 6.28$ per cent. But suppose the initial pressure to have been 200 lbs. absolute, and that the steam is allowed to expand to thirty times its original volume. The heat expended in evaporating a pound of water at 32° into steam at 200 lbs. absolute pressure = 1,198.3 heat units, and the volume of steam so generated = 2.27 cu. ft. The average pressure during expansion would be 29.34 lbs. per square inch and the volume when expanded thirty times would equal 2.27 × 30 = 68.1 cu. ft.

One cubic foot of steam at 29.34 lbs. pressure equals 144 × 29.34 = 4,224.96 ft. lbs., and 68.1 cu. ft. will equal 4224.96 × 68.1 = 287,719.7 ft. lbs. of energy, which divided by the equivalent, 778, equals 370.2 heat units, and the per cent. of efficiency will be $\frac{370.2 \times 100}{1,198.3} = 30.8$ per cent.

Engine efficiency. If the engine is considered merely as a machine for converting into useful work the heat energy in the steam regardless of the cost of fuel, its efficiency may be expressed as follows:

$$\frac{\text{Heat converted into useful work}}{\text{Total heat received in the steam}}$$

Example. Assume an engine to be receiving steam at 95 lbs. absolute pressure, that the consumption of dry steam per horse power per hour equals 20 lbs., that the friction of the engine amounts to 15 per cent., and that the temperature of the feed water is raised from 60° to 170° by utilizing a portion of the exhaust.

In a pound of steam at 95 lbs. absolute there are 1,180.7 heat units, and in a pound of water at 170° there

are 138.6 units of heat, but 28.01 of these heat units were in the water at its initial temperature of 60°. Therefore the total heat added to the water by the exhaust steam equals 138.6 – 28.01 = 110.59 heat units, and the total heat in each pound of steam to be charged up to the engine is 1,180.7 – 110.59 = 1,070.11, and the total for each horse power developed per hour will be 1,070.11 × 20 = 21,402.2 heat units.

A horse power equals 33,000 ft. lbs. per minute, or sixty times 33,000 = 1,980,000 ft. lbs. per hour. From this must be deducted 15 per cent. for friction of the engine, leaving 1,683,000 ft. lbs. for useful work. Dividing this by the equivalent, viz., 778 ft. lbs., gives 2,163.2 heat units as the heat converted into one horse power of work in one hour, and the percentage of efficiency of the engine will be $\frac{2,163.2 \times 100}{21,402.2}$ = 10.1 per cent.

Efficiency of the plant as a whole includes boiler and engine efficiency and is to be figured upon the basis of

$$\frac{\text{Heat converted into useful work}}{\text{Calorific or heat value of fuel}}$$

Horse power constant of an engine is found by multiplying the area of the piston in square inches by the speed of the piston in feet per minute and dividing the product by 33,000. It is the power the engine would develop with one pound mean effective pressure. To find the horse power of the engine, multiply the M. E. P. of the diagram by this constant.

Logarithms. A series of numbers having a certain relation to the series of natural numbers, by means of which many arithmetical operations are made comparatively easy. The nature of the relation will be understood by considering two simple series, such as the following, one proceeding from unity in geomet-

rical progression and the other from 0 in arithmetical progression:

Geom. series, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, etc.
Arith. series, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, etc.

Here the ratio of the geometrical series is 2 and any term in the arithmetical series expresses how often 2 has been multiplied into 1 to produce the corresponding term of the geometrical series. Thus, in proceeding from 1 to 32 there have been 5 steps or multiplications by the ratio 2; in other words, the ratio of 32 to 1 is compounded 5 times of the ratio of 2 to 1. The above is the basic principle upon which common logarithms are computed.

Hyperbolic logarithms. Used in figuring the M. E. P. of a diagram from the ratio of expansion and the initial pressure. Thus, hyperbolic logarithm of ratio of expansion + 1 multiplied by absolute initial pressure and divided by ratio of expansion = mean forward pressure. From this deduct total back pressure and the remainder will be mean effective pressure. The hyperbolic logarithm is found by multiplying the common logarithm by the constant 2.302585. Table 8 gives the hyperbolic logarithms of numbers usually required in calculations of the above nature.

Steam consumption per horse power per hour. The weight in pounds of steam exhausted into the atmosphere or into the condenser in one hour divided by the horse power developed. It is determined from the diagram by selecting a point in the expansion curve just previous to the opening of the exhaust valve and measuring the absolute pressure at that point. Then the piston displacement up to the point selected, plus the clearance space, expressed in cubic feet, will give the volume of steam in the cylinder, which multiplied

Table 8.

Hyperbolic Logarithms.

No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.01	0.0099	3.00	1.0986	5.00	1.6094	7.00	1.9459	9.00	2.1972
1.05	0.0487	3.05	1.1151	5.05	1.6194	7.05	1.9530	9.05	2.2028
1.10	0.0953	3.10	1.1341	5.10	1.6292	7.10	1.9600	9.10	2.2083
1.15	0.1397	3.15	1.1474	5.15	1.6390	7.15	1.9671	9.15	2.2137
1.20	0.1823	3.20	1.1631	5.20	1.6486	7.20	1.9740	9.20	2.2192
1.25	0.2231	3.25	1.1786	5.25	1.6582	7.25	1.9810	9.25	2.2246
1.30	0.2623	3.30	1.1939	5.30	1.6677	7.30	1.9879	9.30	2.2310
1.35	0.3001	3.35	1.2090	5.35	1.6771	7.35	1.9947	9.35	2.2354
1.40	0.3364	3.40	1.2238	5.40	1.6864	7.40	2.0015	9.40	2.2407
1.45	0.3715	3.45	1.2384	5.45	1.6956	7.45	2.0018	9.45	2.2460
1.50	0.4054	3.50	1.2527	5.50	1.7047	7.50	2.0149	9.50	2.2513
1.55	0.4382	3.55	1.2669	5.55	1.7138	7.55	2.0215	9.55	2.2565
1.60	0.4700	3.60	1.2809	5.60	1.7228	7.60	2.0281	9.60	2.2618
1.65	0.5007	3.65	1.2947	5.65	1.7316	7.65	2.0347	9.65	2.2670
1.70	0.5306	3.70	1.3083	5.70	1.7405	7.70	2.0412	9.70	2.2721
1.75	0.5596	3.75	1.3217	5.75	1.7491	7.75	2.0477	9.75	2.2773
1.80	0.5877	3.80	1.3350	5.80	1.7578	7.80	2.0541	9.80	2.2824
1.85	0.6151	3.85	1.3480	5.85	1.7664	7.85	2.0605	9.85	2.2875
1.90	0.6418	3.90	1.3610	5.90	1.7750	7.90	2.0668	9.90	2.2925
1.95	0.6678	3.95	1.3737	5.95	1.7834	7.95	2.0731	9.95	2.2976
2.00	0.6931	4.00	1.3863	6.00	1.7918	8.00	2.0794	10.00	2.3026
2.05	0.7178	4.05	1.3987	6.05	1.8000	8.05	2.0857	10.25	2.3273
2.10	0.7419	4.10	1.4010	6.10	1.8083	8.10	2.0918	10.50	2.3514
2.15	0.7654	4.15	1.4231	6.15	1.8164	8.15	2.0988	10.75	2.3749
2.20	0.7885	4.20	1.4351	6.20	1.8245	8.20	2.1041	11.00	2.3979
2.25	0.8110	4.25	1.4469	6.25	1.8326	8.25	2.1102	12.00	2.4849
2.30	0.8329	4.30	1.4586	6.30	1.8405	8.30	2.1162	13.00	2.5626
2.35	0.8544	4.35	1.4701	6.35	1.8484	8.35	2.1222	14.00	2.6390
2.40	0.8755	4.40	1.4816	6.40	1.8563	8.40	2.1282	15.00	2.7103
2.45	0.8961	4.45	1.4929	6.45	1.8640	8.45	2.1342	16.00	2.7751
2.50	0.9163	4.50	1.5040	6.50	1.8718	8.50	2.1400	17.00	2.8332
2.55	0.9361	4.55	1.5151	6.55	1.8795	8.55	2.1459	18.00	2.8903
2.60	0.9555	4.60	1.5260	6.60	1.8870	8.60	2.1518	19.00	2.9444
2.65	0.9746	4.65	1.5369	6.65	1.8946	8.65	2.1576	20.00	2.9957
2.70	0.9932	4.70	1.5475	6.70	1.9021	8.70	2.1633	21.00	3.0445
2.75	1.0116	4.75	1.5581	6.75	1.9095	8.75	2.1690	22.00	3.0910
2.80	1.0296	4.80	1.5686	6.80	1.9169	8.80	2.1747	23.00	3.0355
2.85	1.0473	4.85	1.5790	6.85	1.9242	8.85	2.1804	24.00	3.1780
2.90	1.0647	4.90	1.5892	6.90	1.9315	8.90	2.1860	25.00	3.2189
2.95	1.0818	4.95	1.5994	6.95	1.9387	8.95	2.1916	30.00	3.3782

by the weight per cubic foot of steam at the pressure as measured will give the weight of steam consumed during one stroke. From this should be deducted the steam saved by compression as shown by the diagram, in order to get a true measure of the economy of the engine. Having thus determined the weight of steam consumed for one stroke, multiply it by twice the number of strokes per minute and by 60, which will give the total weight consumed per hour. This divided by the horse power will give the rate per horse power per hour.

Cylinder condensation and reëvaporation. When the exhaust valve opens to permit the exit of the steam there is a perceptible cooling of the walls of the cylinder, especially in condensing engines when a high vacuum is maintained. This results in more or less condensation of the live steam admitted by the opening of the steam valve; but if the exhaust valve is caused to close at the proper time so as to retain a portion of the steam to be compressed by the piston on the return stroke, a considerable portion of the water caused by condensation will be reëvaporated into steam by the heat and consequent rise in pressure caused by compression.

Ordinates. Parallel lines drawn at equal distances apart across the face of the diagram, and perpendicular to the atmospheric line. They serve as a guide to facilitate the measurement of the average forward pressure throughout the stroke, or the pressure at any point of the stroke if desired.

Eccentric. A mechanical device used in place of a crank for converting rotary into reciprocating motion. An eccentric is in fact a form of crank in which the crank pin, corresponding to the eccentric sheave,

embraces the shaft, but owing to the great leverage at which the friction between the sheave and the strap acts, compared with its short turning leverage, it can only be used to advantage for the purpose named above.

Eccentric throw is the distance from the center of the eccentric to the center of the shaft. This definition also applies to the term "radius of eccentricity."

Eccentric position. The location of the highest point of the eccentric relative to the center of the crank pin, measured or expressed in degrees.

Angular advauce. The distance that the high point of the eccentric is set ahead of a line at right angles with the crank. In other words, the lap angle plus the lead angle. If a valve had neither lap nor lead, the position of the high point of the eccentric would be on a line at right angles with the crank; as for instance, the crank being at 0° the eccentric would stand at 90°.

Valve travel. The distance covered by the valve in its movement. It equals twice the throw of the eccentric. This refers to engines having a fixed cut off. In the case of an engine with a variable automatic cut off the travel of the cut off valve is regulated by the governor.

Lap. The amount that the ends of the valve project over the edges of the ports when the valve is at mid travel.

Outside or steam lap. The amount that the end of the valve overlaps or projects over the outside edge of the steam port.

Inside lap. The lap of the inside or exhaust edge of the valve over the inside edge of the port.

Lead. The amount that the port is open when the

crank is on the dead center. The object of giving a valve lead is to supply a cushion of live steam which, in conjunction with that already confined in the clearance space by compression, shall serve to bring the moving parts of the engine to rest quietly at the end of the stroke, and also quicken the action of the piston in beginning the return stroke.

Compression. Closing of the exhaust passage before the steam is entirely exhausted from the cylinder. A certain quantity of steam is thus compressed into the clearance space.

Throttling governor. Used to regulate the speed of engines having a fixed cut off. The governor controls the position of a valve in the steam pipe, opening or closing it according as the engine needs more or less steam in order to maintain a regular speed.

Automatic or variable cut off. In engines of this type the full boiler pressure is constantly in the valve chest and the speed of the engine is regulated by the governor controlling the point of cut off, causing it to take place earlier or later according as the load on the engine is lighter or heavier.

Fixed cut off. This term is applied to engines in which the point of cut off remains the same regardless of the load, the speed being regulated by a throttling governor as explained above.

Isochronal or shaft governor. This device in which the centrifugal and centripetal forces are utilized, as in the fly ball governor, is generally applied to automatic cut off engines having reciprocating or slide valves. It is attached to the crank shaft and its function is to change the position of the eccentric, which is free to move across the shaft within certain prescribed limits, but is at the same time attached to the

Table 9.

Areas and Circumferences of Circles.

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
.25	.049	.7854	15.5	188.692	48.694	31	754.769	97.389
.5	.1963	1.5708	16	201.062	50.265	31.25	766.992	98.175
1.0	.7854	3.1416	16.25	207.394	51.051	31.5	799.313	98.968
1.25	1.2271	3.9270	16.5	213.825	51.836	32	804.249	100.53
1.5	1.7671	4.7124	17	226.980	53.407	32.25	816.86	101.31
2	3.1416	6.2832	17.25	233.705	54.192	33	855.30	103.67
2.25	3.9760	7.0686	17.5	240.520	54.978	33.25	868.30	104.45
2.5	4.9087	7.8540	18	254.469	56.548	33.5	881.41	105.24
3	7.0686	9.4248	18.25	261.587	57.334	34	907.92	106.81
3.25	8.2957	10.210	18.5	268.803	58.119	34.25	921.32	107.60
3.5	9.6211	10.995	19	283.529	59.690	34.5	934.82	108.38
4	12.566	12.566	19.25	291.039	60.475	35	962.11	106.95
4.25	14.186	13.351	19.5	298.648	61.261	35.25	975.90	110.74
4.5	15.904	14.137	20	314.160	62.832	35.5	989.80	111.52
5	19.635	15.708	20.25	322.063	63.617	36	1017.8	113.09
5.25	21.647	16.493	20.5	330.064	64.402	36.25	1032.06	113.88
5.5	23.758	17.278	21	346.361	65.973	36.5	1046.35	114.66
6	28.274	18.849	21.25	354.657	66.759	37	1075.21	116.23
6.25	30.679	19.635	21.5	363.051	67.544	37.25	1089.79	117.01
6.5	33.183	20.420	22	380.133	69.115	37.5	1104.46	117.81
7	38.484	21.991	22.25	388.822	69.900	38	1134.11	119.38
7.25	41.282	22.776	22.5	397.608	70.686	38.25	1149.08	120.16
7.5	44.178	23.562	23	415.476	72.256	38.5	1164.15	120.95
8	50.265	25.132	23.25	424.557	73.042	39	1194.59	122.52
8.25	53.456	25.918	23.5	433.731	73.827	39.25	1209.95	123.30
8.5	56.745	26.703	24	452.390	75.398	39.5	1225.42	124.09
9	63.617	28.274	24.25	461.864	76.183	40	1256.64	125.66
9.25	67.200	29.059	24.5	471.436	76.969	40.25	1272.39	126.44
9.5	70.882	29.845	25	490.875	78.540	40.5	1288.25	127.23
10	78.540	31.416	25.25	500.741	79.325	41	1320.25	128.80
10.25	82.516	32.201	25.5	510.706	80.110	41.25	1336.40	129.59
10.5	86.590	32.986	26	530.930	81.681	41.5	1352.65	130.37
11	95.033	34.557	26.25	541.189	82.467	42	1385.44	131.94
11.25	99.402	35.343	26.5	551.547	83.252	42.25	1401.98	132.73
11.5	103.869	36.128	27	572.556	84.823	42.5	1418.62	133.51
12	113.097	37.699	27.25	583.208	85.608	43	1452.20	135.08
12.25	117.859	38.484	27.5	593.958	86.394	43.25	1469.13	135.87
12.5	122.718	39.270	28	615.753	87.964	43.5	1486.17	136.65
13	132.732	40.840	28.25	626.798	88.750	44	1520.53	138.23
13.25	137.886	41.626	28.5	637.941	89.535	44.25	1537.86	139.01
13.5	143.130	42.411	29	660.521	91.106	44.5	1555.28	139.80
14	153.938	43.982	29.25	671.958	91.891	45	1590.43	141.37
14.25	159.485	44.767	29.5	683.494	92.677	45.25	1608.15	142.15
14.5	165.130	45.553	30	706.860	94.248	45.5	1625.97	142.94
15	176.715	47.124	30.25	718.690	95.033	46	1661.90	144.51
15.25	182.654	47.909	30.5	730.618	95.818	46.25	1680.01	145.29

TABLE 9—*Continued.*

Diam.	Area.	Circum.	Diam.	Area.	Circum.	Diam.	Area.	Circum.
46.5	1698.23	146.08	62 25	3043.47	195.56	78	4778.37	245.04
47	1734.94	147.65	62.5	3067.96	196.35	78.25	4809.05	245.83
47.25	1753.45	148.44	63	3117.25	197.92	78.5	4839.83	246.61
47.5	1772.05	149.22	63.25	3142.04	198.71	79	4901.68	248.19
48	1809.56	150.79	63.5	3166.92	199.50	79.25	4932.75	248.97
48.25	1828 46	151.58	64	3216.99	201.06	79 5	4963.92	249.76
48.5	1847.45	152.36	64.25	3242.17	201.85	80	5026.56	251.33
49	1885.74	153.93	64.5	3267.46	202.68	80.5	5089.58	252.90
49.25	1905.03	154.72	65	3318.31	204.20	81	5153.00	254.47
49.5	1924.42	155.50	65.25	3343.88	204.99	81.5	5216.82	256.04
50	1963.50	157.08	65.5	3369.56	205.77	82	5281.02	257.61
50.25	1983.18	157.86	66	3421.20	207.34	82.5	5345.62	259.18
50.5	2002.96	158.65	66.25	3447.16	208.13	83	5410.62	260.75
51	2042.82	160.22	66.5	3473.23	208.91	83.5	5476.00	262.32
51.25	2062.90	161.00	67	3525.66	210.49	84	5541.78	263.89
51.5	2083.07	161.79	67.25	3552.01	211.27	84.5	5607.95	265.46
52	2123.72	163.36	67.5	3578.47	212.06	85	5674.51	267.04
52.25	2144.19	164.14	68	3631.68	213.63	85.5	5741.47	268.60
52.5	2164.75	164.19	68.25	3658.44	214.41	86	5808.81	270.17
53	2206.18	166.50	68.5	3685.29	215.20	86.5	5876.55	271.75
53.25	2227.05	167.29	69	3739.28	216.77	87	5944.66	273.32
53.5	2248.01	168.07	69.25	3766.43	217.55	87.5	6013.21	274.89
54	2290.22	169.64	69.5	3793.67	218.34	88	6082.13	276.46
54.25	2311.48	170.43	70	3848.46	219.91	88.5	6151.44	278.03
54.5	2332.83	171.21	70.25	3875.99	220.70	89	6221.15	279.60
55	2375.83	172.78	70.5	390 .63	221.48	89.5	6291.25	281.17
55.25	2397.48	173.57	71	3959.20	223.05	90	6371.64	282.74
55.5	2419.22	174.35	71.25	3987.13	223.84	90.5	6432.62	284.31
56	2463.01	175.92	71.5	4015.16	224.62	91	6503.89	285.88
56.25	2485.05	176.71	72	4071.51	226.19	91.5	6573.56	287.46
56.5	2507.19	177.5	72.25	4099.83	226.98	92	6647.62	289.03
57	2551.76	179.07	72 5	4128.25	227.75	92.5	6720.07	290.60
57.25	2574.19	179.85	73	4185.39	229.34	93	6792.92	292.17
57.5	2596.72	180.64	73.25	4214.11	230.12	93.5	6866.16	293.74
58	2642.08	182.21	73.5	4242.92	230.91	94	6939.79	295.31
58.25	2664.91	182.99	74	4300.85	232.48	94.5	7013.81	296.88
58.5	2687.83	183.78	74.25	4329.95	233.26	95	7088.23	298.45
59	2733.97	185.35	74.5	4359.16	234.05	95.5	7163.04	300.02
59.25	2757.19	186.14	75	4417.87	235.62	96	7238.25	301.59
59.5	2780.51	186.92	75.25	4447.37	236.40	96.5	7313.80	303.16
60	2827.44	188.49	75.5	4476.97	237.19	97	7389.81	304.73
60.25	2851.05	189.28	76	4536.37	238.76	97.5	7466.22	306.30
60.5	2874.76	190.06	76.25	4566.36	239.55	98	7542.89	307.88
61	2922 47	191.64	76.5	4596.35	240.33	98.5	7620.09	309 44
61.25	2946.47	192.42	77	4656.63	241.90	99	7697.70	311.02
61.5	2970.57	193.21	77 25	4686.92	242.69	99.5	7775.63	312.58
62	3019.07	194.78	77.5	4717.30	243.47	100	7854.00	314.16

governor. The angular advance of the eccentric is thus increased or diminished, in fact is entirely under the control of the governor, and cut off occurs earlier or later according to the demands of the load on the engine.

Adjustable cut off. One in which the point of cut off may be regulated or adjusted by hand by means of a hand wheel and screw attached to the valve stem, the supply of steam being regulated by a throttling governor.

Questions

1. What is absolute pressure?
2. What is gauge pressure?
3. What is initial pressure?
4. What is terminal pressure and how may it be ascertained theoretically?
5. What is back pressure?
6. What is absolute back pressure?
7. What is meant by ratio of expansion?
8. What does the term wire drawing mean when applied to an indicator diagram?
9. What is condensor pressure?
10. What does the term vacuum imply?
11. What is absolute zero?
12. What is meant by the term piston displacement?
13. What is piston clearance?
14. What is steam clearance?
15. What is a horse power?
16. What is meant by piston speed?
17. Define Boyle's law of expanding gases.
18. What is an adiabatic curve?
19. What is an isothermal curve?
20. What is the first law of thermodynamics?
21. What is the unit of work?

22. Define the first law of motion.
23. What is momentum?
24. What is the maximum theoretical duty of steam?
25. What is meant by the term steam efficiency?
26. How may the term engine efficiency be defined?
27. What is meant by the term efficiency of the plant, and how may it be ascertained?
28. How is the horse power constant of an engine found, and what does it mean?
29. What are common logarithms?
30. What are hyperbolic logarithms, and how are they found?
31. What are ordinates as applied to an indicator diagram?
32. What is an eccentric?
33. What is meant by the throw of an eccentric?
34. What is meant by position of the eccentric?
35. What is angular advance?
36. What is valve travel?
37. What is lap?
38. What is inside lap?
39. What is outside lap?
40. What is lead?
41. What is a throttling governor?
42. What is meant by the term fixed cut off?
43. What is meant by an automatic cut off?
44. What is an isochronal governor?
45. What is an adjustable cut off?

CHAPTER IX

DIAGRAM ANALYSIS

Diagram analysis—Figure illustrating the various points in an indicator diagram—Disadvantage of unequal cut off—Diagram from compound condensing engine—Rules for finding M. E. P. when the initial and terminal pressures are known, and the ratio of expansion—Equalizing the work done in the high and low pressure cylinders—Misleading diagrams caused by dirt in indicator cylinder—Diagrams showing effect of cramped exhaust—Table of factors for calculating the steam consumption from the terminal pressure.

In the following study of indicator diagrams all the illustrations are reproductions of actual diagrams taken under ordinary working conditions. Figs. 50 and 51 are here introduced in order to define the different

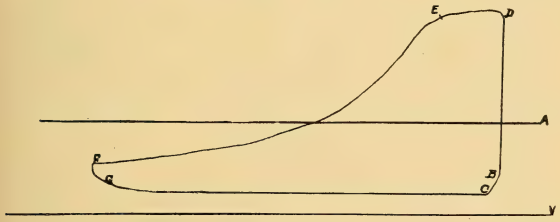


FIGURE 50.

points, lines and curves. Fig. 50 was taken from a large vertical engine with the corliss valve motion.

The engine being of slow speed and extremely long stroke (10 ft.) with a clearance of but 1 per cent., the compression beginning at C and ending at B is somewhat lighter than is ordinarily given to shorter stroke

engines. From B to D is the admission line, which being practically perpendicular to the atmospheric line A, shows sufficient lead and ample port area. From D to E is the steam line. Cut off occurs at E, and from E to F is the expansion curve. At F the point of release is quite sharply defined, as it should be. From F to G is the exhaust line, and from G to C the line of back pressure, sometimes called the line of counter pressure for the reason that the pressure indicated by it acts counter or in opposition to the forward pressure of the steam on the piston. This engine is a

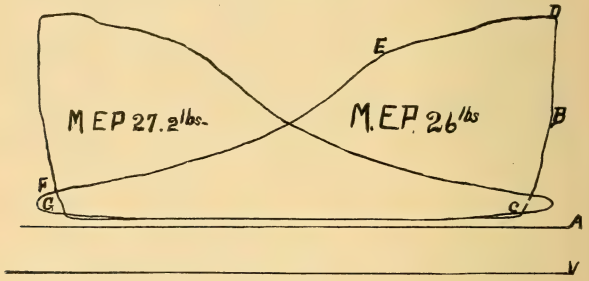


FIGURE 51.

simple condensing engine and the nearness of the back pressure line to the line of perfect vacuum V shows that an excellent vacuum was maintained in the condenser.

Fig. 51 is from a Buckeye automatic cut off engine having a shaft governor and what is termed a riding cut off, that is the cut off valve slides to and fro on the back of the main valve. The engine is horizontal non-condensing, the cylinder being 28 in. bore by 56 in. stroke, and, at the time the diagram was taken,

developed 357.58 horse power with a piston speed of 728 ft. per minute. The steam consumption per I. H. P. per hour was 26 lbs., a rather high rate, but this was owing to the fact that the engine was located too far from the boilers, and as there were a large number of elbows in the steam pipe the pressure was greatly reduced at the engine. Thus wire drawing of the steam was caused, which is plainly indicated by the downward inclination of the steam line, D E.

In a well proportioned engine having a steam pipe of sufficiently large area, the steam line should parallel the atmospheric line up to the point of cut off. Fig. 51 indicates proper release of the steam at F, and the back pressure from G to C, which is 3 lbs. above the atmospheric line, shows a reasonably free passage of the exhaust steam.

Figs. 52 to 57 illustrate diagrams from three new vertical corliss engines supplying power for an electric lighting plant, which the author was requested to test and adjust after they had been in operation a few months. The valves had previously been set by the erecting engineer at the time the engines were set up. Each one of these engines exhausted into a separate condenser of the Jet type, into which the condensing water was forced under pressure and from which the overflow was discharged by gravity into a sewer. There was no air pump and as a consequence the vacuum maintained was very low, usually from 10 to 15 in., and at times still less, so that the beneficial results of condensing were only partially realized.

For convenience the diagrams from each engine will be treated in numerical order, beginning with engine No. 1. This engine was 24×48 in., running 70 R. P. M., with a boiler pressure of 68 lbs. A 40 spring was

used in the indicator. The principal defect was the lack of sufficient lead on both ends, as indicated by the inclination inward of the admission lines and the rounded corners of the steam lines at the beginning of

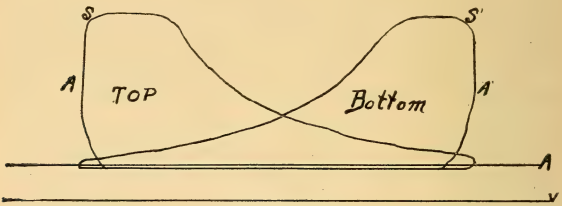


FIGURE 52.

the stroke. (See Fig. 52.) There was also more compression, especially on the bottom end, than was necessary, considering the size of the engine and the speed. The necessary changes having been made, the indicator was again applied and the diagram Fig. 53 was

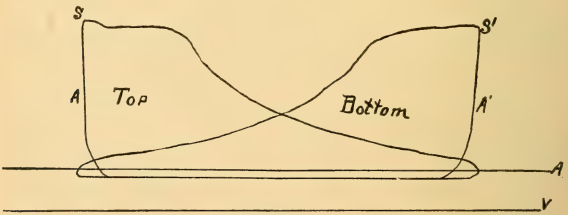


FIGURE 53.

obtained, which shows the distribution of the steam to be satisfactory, although at the time of taking this diagram the boiler pressure was only 60 lbs., while it should have been 68 or 70 lbs., because with the latter

pressure still better results could have been attained. The I. H. P. was 235 and the steam used per I. H. P. per hour was 18 lbs.

Fig. 54 is the original diagram from engine No. 2,

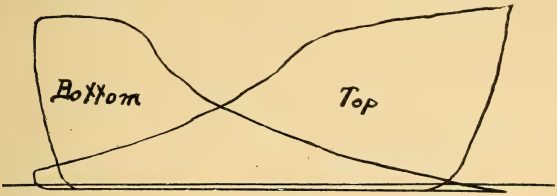


FIGURE 54.

and shows bad valve adjustment all around, with the exception of lead on the top end. The variation in the points of cut off is the worst feature; cut off taking place on the bottom at 29 per cent. of the stroke, while on the top end it does not occur until

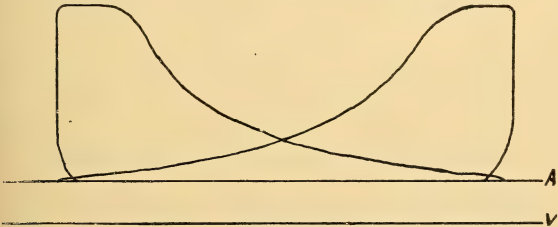


FIGURE 55.

the piston has traveled through 42 per cent. of the stroke. There is more compression also than is needed. This engine was 18 × 42 in., running at a speed of 78 R. P. M., and the steam consumption,

according to diagram Fig. 54, was 33 lbs. per I. H. P. per hour. Having equalized the cut off and reduced the compression by making the necessary changes in the valve gear, the indicator was again applied, resulting in diagram Fig. 55, which may be considered prac-

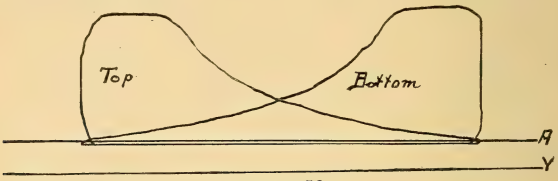


FIGURE 56.

tically perfect. The boiler pressure was 68 lbs. and the spring used was a No. 40. The steam consumption was reduced to 22 lbs. per I. H. P. per hour as compared to 33 lbs. in Fig. 54.

Figs. 56 and 57 represent diagrams from engine No. 3, which was the same size as No. 1, viz., 24 × 48 in.,

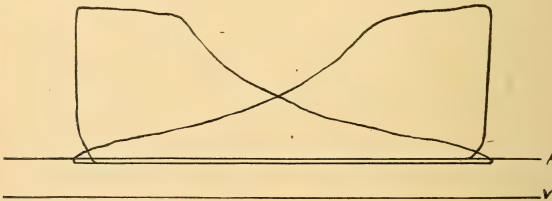


FIGURE 57.

and running at 72 R. P. M. The original diagram, Fig. 56, shows too little lead on both ends, but especially on the top. There is also lack of compression on the bottom end. The boiler pressure was 60 lbs. and the scale of spring 40. Fig. 57, taken after the

necessary adjustments had been made, shows much better valve performance. The horse power developed was 251 and the steam consumption was 20.5 lbs. per I. H. P. per hour. The rather high rate of steam consumption for this engine as compared with engine No. 1, which was the same size but consumed only 18 lbs. of steam per I. H. P. per hour, was due to two causes. First, a low vacuum; second, low initial pressure necessitating a late cut off.

Figs. 58 to 61, inclusive, are diagrams from a Bullock horizontal non-condensing corliss engine which had

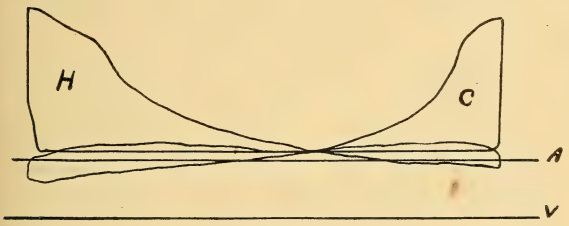


FIGURE 58.

been running about eight or nine months when it fell to the author's lot to apply the indicator to the engine, not only for the purpose of adjusting the valve motion, but also to make a series of tests for the purpose of ascertaining the amount of power delivered by the engine to each one of several different departments which were receiving power from this source.

The dimensions of the engine were as follows: bore of cylinder, 32 in.; stroke, 5 ft. At the time Fig. 58 was taken the engine was making 62 R. P. M. and the boiler pressure was only 50 lbs. A 30 spring was used. Although the load on the engine was very light

at the time, yet the diagram served as a guide to some extent in setting the valves, and by taking off the bonnets from the valve chests and making the necessary changes in the adjustment by the marks on the valves

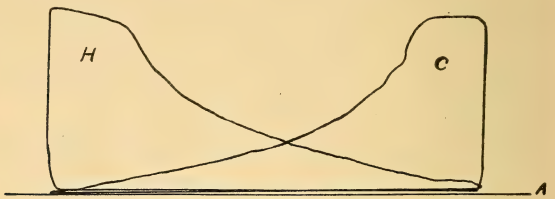


FIGURE 59.

a pretty fair job was made of it, as will be seen by referring to Fig. 59. The reducing motion was a pantograph, described in Chapter VIII, and as it is very easy to vary the travel of the paper drum with this motion, diagrams of different lengths were taken until the one which appeared to be the most satisfac-

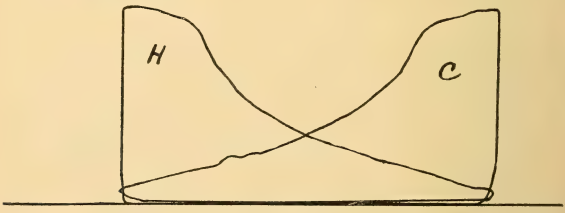


FIGURE 60.

tory was obtained. The slight hump in the expansion curve immediately after cut off was probably caused by a speck of dirt or grit which momentarily checked the indicator piston on the down stroke. The com-

pression on the crank end is not sufficient and the exhaust valve rod on that end was slightly lengthened, resulting in the production of diagram Fig. 60. In this diagram the familiar hump in the crank end expansion curve reappears, but in a different location, being nearer the end of the stroke. It will also be noticed that the length of Fig. 60 has been considerably reduced from that of Figs. 58 and 59, it being about one inch shorter.

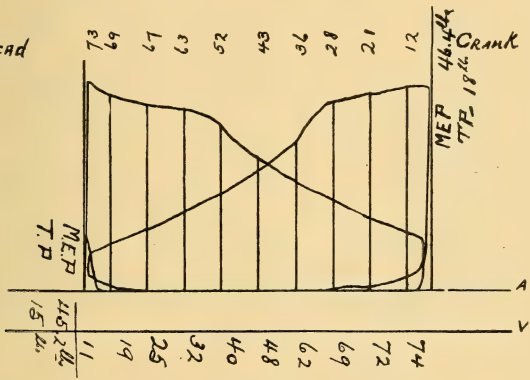


FIGURE 61.

The boiler pressure and the load on this engine were gradually increased from time to time, from 50 lbs. and a light load, (as shown by Fig. 58) to 60 lbs. and 335 horse power, (as indicated by Fig. 59 taken some three months later) and when Fig. 61 was taken, about two years and eight months later, the boiler pressure had been increased to 87 lbs. and the I. H. P. was over 700.

Diagram Fig. 61 shows good economy in the use of

steam in spite of the fact that the cut off occurs rather late. There is no back pressure worth mentioning, the back pressure line forming part of the atmospheric line through the largest part of the stroke. The reason for this is that the areas of the exhaust ports as well as the exhaust pipe were sufficiently large to permit a free passage for the steam. The exhaust pipe, also, was made as short and direct as possible and all superfluous elbows were dispensed with. The steam con-

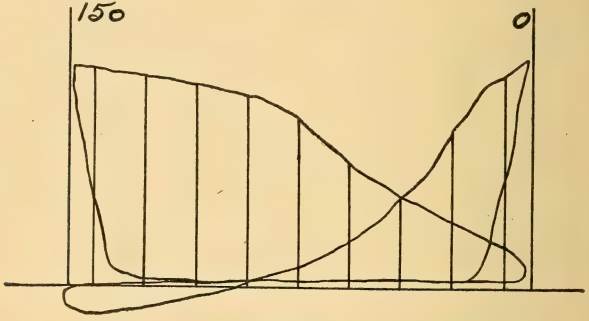


FIGURE 62.

sumed per I. H. P. per hour as per diagram Fig. 61 was 22.3 lbs., and the horse power developed was 710.6.

Figs. 62 to 64, inclusive, represent diagrams from a Buckeye engine 24 × 48 in., and are introduced for the purpose of emphasizing the need of caution and good judgment in setting valves by the indicator when the load on the engine is variable. Fig. 62, which was the first to be taken, would seem to indicate that the valve was badly adjusted, but when Fig. 63 was taken immediately afterwards, the cause of the trouble became apparent. The engine was furnishing power for

operating an electric street railway on a small scale, and the variation in the points of cut off was caused by the stopping and starting of the cars.

Fig. 63 is a notable example of the quick and delicate action of the shaft governor, as it will be seen that during four successive revolutions there was a different load each time, as shown by the diagram from the crank end.

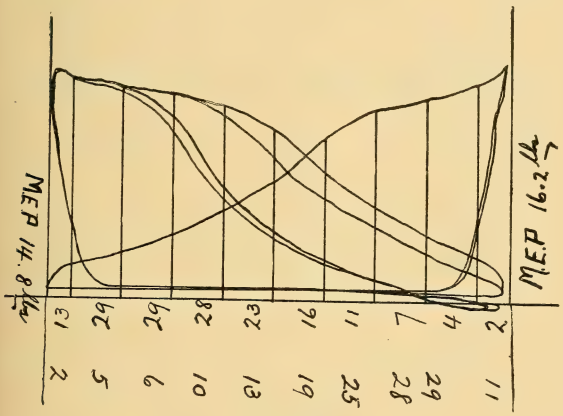


FIGURE 63.

Fig. 64 was secured by quick manipulation of the instrument when it was known that the load was to be steady for a few seconds.

Fig. 65 is from an Atlas single valve automatic cut off engine with shaft governor. This engine was 16 × 24 in., running at 105 R. P. M., and at the time the diagram was taken the boiler pressure was only 50 lbs. The spring used was a No. 30. The diagram is a

fairly good one for the type of engine. Owing to the variation in the angular advance of the single eccentric

FIGURE 64.

actuated by a shaft governor, the degree of compression varies with the point of cut off in the single valve engine, the compression being higher with an early

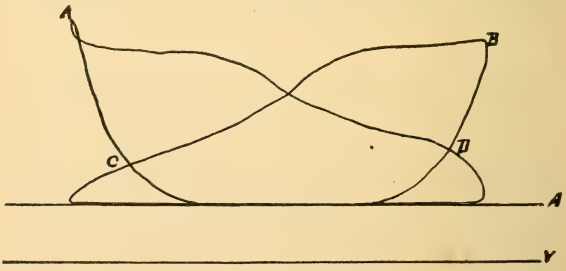


FIGURE 65.

cut off than it is when cut off occurs later in the stroke. The loop at A is caused by too much lead

which, together with the compression, caused a momentary rise in the pressure above the normal. The lead at B is approximately correct. The differ-

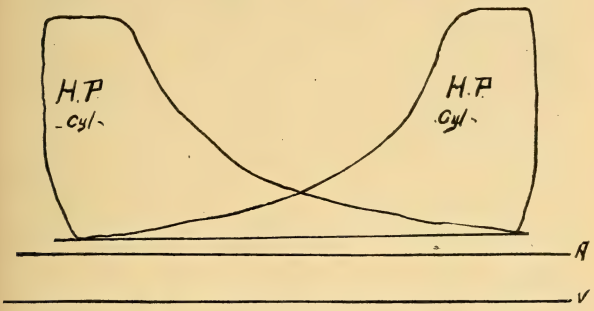


FIGURE 66.

ence in terminal pressures at C and D is the result of shifting of the points of cut off caused by variations in the load. The back pressure lines are almost identical with the atmospheric line, showing that the exhaust is

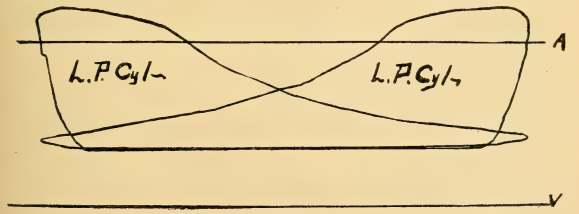


FIGURE 67.

in no way restricted or cramped. I. H. P. is 65.7 and steam consumption 21 lbs. per I. H. P. per hour.

Figs. 66 and 67 are diagrams taken from a cross

compound condensing corliss engine. The high pressure cylinder was 24×48 in., and the low pressure cylinder was 44×48 in. The steam from the high pressure exhausted into a receiver and from thence into the low pressure cylinder. The receiver pressure was 5.3 lbs. above atmospheric pressure. The ratio of piston areas was 3.36 to1. That is, the area of the low pressure piston was 3.36 times the area of the high pressure piston, which was about the correct ratio for the pressure carried, viz., 84 lbs. gauge or 99 lbs. absolute. A No. 40 spring was used on the high pressure and a No. 12 on the low pressure cylinder. The number of expansions in the two cylinders was 14. Thus, the ratio of expansion in the high pressure cylinder was 4.5 and in the low pressure the ratio was 3.1. Then $4.5 \times 3.1 = 14$; or, Thus, initial pressure = 99 lbs. absolute, terminal pressure in L. P. cylinder = 7 lbs. absolute; then $99 \div 7 = 14$.

To illustrate the process of finding the M. E. P. without the use of ordinates when the absolute initial and terminal pressures and the number of expansions in each cylinder are known, the following problems will be worked out:

Find M. E. P. in L. P. cylinder.

First, find initial pressure.

Rule. T. P. multiplied by number of expansions. Thus, $7 \times 3.1 = 21.7$ lbs. absolute initial pressure in L. P. cylinder.

Second, find mean forward pressure (M. F. P.).

Rule. Multiply initial pressure by hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus the hyperbolic logarithm of 3.1 = 1.1314, to which add 1 = 2.1314. Then $\frac{21.7 \times 2.1314}{3.1} = 14.9$ lbs. M. F. P. Deduct from

this the back pressure, which was 5 lbs. absolute. Thus, $14.9 - 5 = 9.9$ lbs. M. E. P. in L. P. cylinder.

Next find M. E. P. in H. P. cylinder.

First, find T. P. in H. P. cylinder.

This will equal the initial pressure in the L. P. cylinder + 2 per cent for loss in the receiver. Thus, $21.7 + .4 = 22.1$ lbs., terminal pressure in H. P. cylinder.

Second, find initial pressure in H. P. cylinder.

Rule. Multiply T. P. by number of expansions. Thus, $22.1 \times 4.5 = 99.4$ lbs., absolute initial pressure in H. P. cylinder.

Third, find mean forward pressure (M. F. P.).

The hyperbolic logarithm of $4.5 = 1.5041$, add $1 = 2.5041$. Then $\frac{99.4 \times 2.5041}{4.5} = 55$ lbs., M. F. P. in H. P. cylinder. Deduct back pressure 22.1; thus, 55 lbs. $- 22.1$ lbs. $= 32.9$ lbs., M. E. P. in H. P. cylinder.

The ratio of piston areas being 3.36 to 1, it may be of interest to pursue the subject a little farther and ascertain how the distribution of the steam in the two cylinders corresponds to the ratio of areas. The ratio and pressures may be expressed as follows:

Ratio of areas—H. P. cylinder, 1; L. P. cylinder, 3.36.

M. E. P.—H. P. cylinder, 32.9; L. P. cylinder, 9.9 lbs.

which is very nearly correct; sufficiently so for all practical purposes, and clearly demonstrates that with the intelligent use of the indicator it is possible to so adjust the valves and establish the points of cut off on a compound or triple expansion engine that the work done in each cylinder will be practically the same. As for instance, the product of the area of the H. P. piston and the M. E. P. = 14,883.6 lbs., and that of the L. P. piston × M. E. P. = 15,052.9 lbs., a difference of only 169.3 lbs. If the two products had been equal,

the horse power exerted in the two cylinders would have been the same. As it was, the horse power of the H. P. cylinder was 263.4 and that of the L. P. cylinder was 266.4, showing a difference of only three horse power in the amount of work done in each cylinder.

Fig. 68 was taken from one of a pair of Fishkill corliss engines connected to a common crank shaft. The engines were each 24 × 48 in., and run at 65 R. P. M., with a boiler pressure of 65 lbs. They were equipped with a jet condenser and a bucket plunger air pump served for both engines. These engines had been in

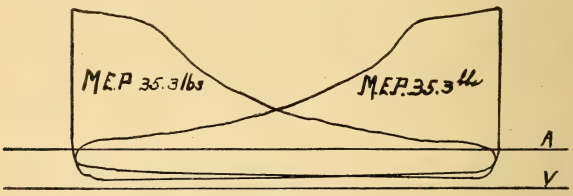


FIGURE 68.

continuous service for nearly seventeen years when the author was called upon to indicate them and adjust the valves. A diagram taken at the same time from the mate of this engine was very nearly an exact counter part of Fig. 68. The horse power, as shown by Fig. 68, was 248, and the steam per I. H. P. per hour was 15.2 lbs. The vacuum gauge showed 27 in. and a 50 spring was used.

Figs. 69 and 70 are from an old Fishkill corliss engine 16 × 42 in., to which the author applied the indicator after he had set the valves, according to the ordinary rules for valve setting, by the marks placed

on the ends of the valves and valve chests. These diagrams are introduced especially for the purpose of showing the need of exercising the greatest of care to prevent dirt or grit of any kind from getting into the

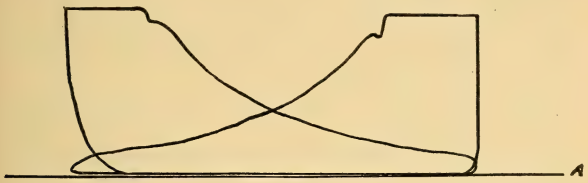


FIGURE 69.

indicator cylinder. After the indicator pipes had been blown out sufficiently, as it was thought, the indicator, which was a thoroughly reliable instrument, was attached and diagram Fig. 69 was obtained. It showed the valve adjustment to be very nearly correct, but the perfectly straight steam lines and the sharp

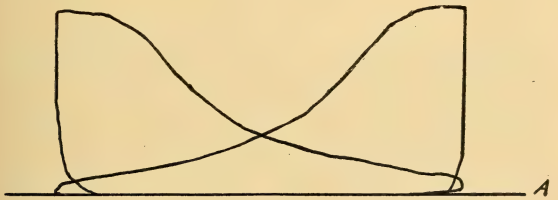


FIGURE 70.

corners and sudden drop at cut off were a puzzle, especially in an old engine where the valves and valve seats were known to be much worn down. After taking several more diagrams with precisely the same

result, the indicator was removed, and upon taking out the piston a quantity of dirt was found on it and also on the inside of the cylinder. This fully explained the cause of the sharp corners, etc., on the diagram. After the indicator had been cleaned and oiled it was again connected and Fig. 70 was produced, which is a truthful presentation of the performance of the steam in the cylinder.

Many diagrams are misleading, owing to causes similar to the above, and a diagram with too sharp angles at cut off or release should be regarded with suspicion until it is proved beyond all doubt to be truthful.

FIGURE 71.

Fig. 71 represents a diagram from a vertical non-condensing engine 14 × 16 in. with riding cut off, which the author was called upon to adjust. This engine was nearly new, having been run but a few months, and although the size of it was ample to do all the work required, yet it had failed, so far, to supply one-half the power needed. After taking the diagram and making a few outside investigations, the cause of the trouble was apparent. Indeed, the wonder was that the engine had supplied as much power as it had under the circumstances.

First. It was situated too far from the boiler plant, being fully 1,200 ft., and although a pressure of 85 lbs.

was carried at the boilers and the steam was conveyed through a 6-inch pipe, yet owing to the many drains on the pipe for heating buildings, running other small engines, etc., by the time the steam reached the engine in question the pressure was reduced so much that a 30 spring was found to be too strong, although that was the scale of Fig. 71.

Second, the end of the exhaust pipe was found to be submerged in a nearby pond of water to which it had been carried, probably with a view of making a condensing engine out of it! It was also found that

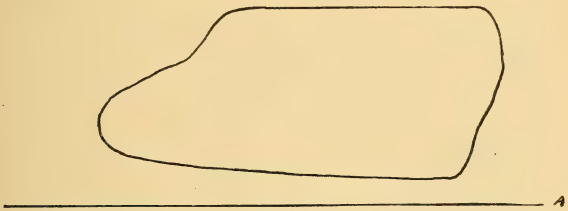


FIGURE 72.

there were no less than four superfluous elbows in the exhaust pipe that could easily be dispensed with. The diagram shows that the cut off was practically useless. That the back pressure was nearly 6 lbs. above the atmosphere, and that the engine was using 55 lbs. of steam and 7 lbs. of coal per horse power per hour, all of which conditions were about as bad as they could be.

After increasing the lead and adjusting the cut off a No. 16 spring was used and Fig. 72 was produced which, although still showing late admission, is an improvement over the original diagram. The initial

pressure being only 30 lbs. above the atmosphere, further work with the indicator was deferred until changes were made in the steam and exhaust pipes, by which the initial pressure was increased to 55 lbs. and the exhaust pipe was freed of extra turns and raised from its watery grave into the open air. The engine has since then given perfect satisfaction.

Fig. 73 is from a Buckeye automatic cut off engine 18 × 36 in. The engine had been running for several years with the valves in the condition shown by the diagram, and in the meanwhile, the load having been increased from time to time, the engine finally refused

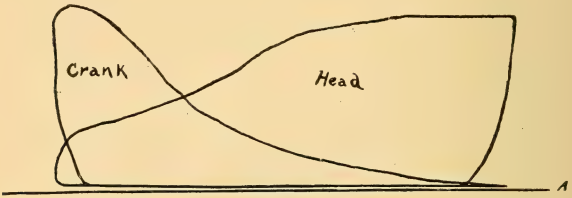


FIGURE 73.

to run up to speed and something had to be done. The superintendent of the plant said that he had an idea that something was the matter with the engine but could not ascertain what it was, and so he finally called upon the author to apply the indicator. The result was that diagram Fig. 73 was obtained, showing that the principal cause of the trouble was unequal cut off. After equalizing the cut off and increasing the lead on the crank end by a small fraction diagram Fig. 74 was taken, and after this the engine gave no further trouble. The depression in the steam lines might have been rectified to some extent by increasing

the boiler pressure, thus giving a higher initial pressure and an earlier cut off. The speed of the engine was 94 R. P. M., with a boiler pressure of 70 lbs. A 40 spring was used with the indicator.

In order to more fully illustrate the process of ascertaining the M. E. P. without dividing the diagram into ordinates, the following computation is given together with rules, etc. In this process two important factors are necessary, viz., the absolute initial pressure and the absolute terminal pressure, and they can both be obtained from the diagram by measuring with the

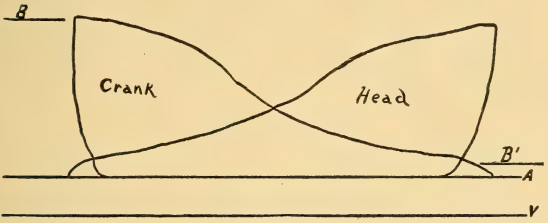


FIGURE 74.

scale adapted to the spring used. Thus, in Fig. 74 the absolute initial pressure measured from the line of perfect vacuum V to line B is 77 lbs., and the absolute terminal pressure measured from V to line B′ is 21 lbs. The ratio, or number of expansions, is found thus:

Rule. Divide the absolute initial pressure by the absolute terminal pressure; thus, $77 \div 21 = 3.65$ = number of expansions.

Second. Find mean forward pressure.

Rule. Multiply absolute initial pressure by the hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus,

referring to Table 8, it will be seen that the hyperbolic logarithm of 3.65 is 1.2947, to which 1 must be added. Then $\frac{77 \times 2.2947}{3.65} = 48.4$ lbs., which is the absolute mean forward pressure. From this deduct the absolute back pressure, which is 16 lbs. or 1 lb. above atmosphere; thus, $48.4 - 16 = 32.4$ lbs. M. E. P.

Third. Find I. H. P.

Area of piston minus one-half area of rod × M. E. P. × piston speed in feet per minute, divided by 33,000. Thus (the diameter of rod being 3 in.), $\frac{250.96 \times 32.4 \times 564}{33000} = 138.9$ I. H. P.

The steam consumption per I. H. P. per hour may also be computed by means of Table 10, which was originally calculated by Mr. Thomson, and is based upon the following theory:

TABLE 10.

T. P.	W.	T. P.	W.	T. P.	W.
3	117.30	13	466.57	23	798.10
3.5	135.75	13.5	483.43	23.5	814.39
4	153.88	14	500.22	24	830.64
4.5	171.94	14.5	517.07	24.5	846.96
5	186.75	15	533.85	25	863.25
5.5	207.60	15.5	550.64	25.5	879.49
6	225.24	16	567.36	26	895.70
6.5	242.97	16.5	584.10	26.5	911.86
7	260.54	17	600.78	27	927.99
7.5	278.06	17.5	617.40	27.5	944.07
8	295.44	18	633.96	28	960.12
8.5	312.80	18.5	650.46	28.5	976.27
9	330.03	19	666.90	29	992.38
9.5	347.27	19.5	683.38	29.5	1008.46
10	364.40	20	699.80	30	1024.50
10.5	381.57	20.5	716.27	30.5	1040.51
11	398.64	21	732.69	31	1056.48
11.5	415.73	21.5	749.06	31.5	1072.42
12	432.72	22	765.38	32	1088.32
12.5	449.69	22.5	781.76	32.5	1104.35

A horse power = 33,000 ft. lbs. per minute, or 1,980,000 ft. lbs. per hour, or 1,980,000 × 12 = 23,760,000 in. lbs. per hour, meaning that the same amount of energy required to lift 33,000 lbs. one foot high in one minute of time would lift 23,760,000 lbs. one inch high in one minute of time. Now if an engine were driven by a fluid that weighed one pound per cubic inch, and the mean effective pressure of this fluid upon the piston was one pound per square inch, it would require 23,760,000 lbs. of the fluid per horse power per hour. But, if in place of the heavier fluid we substitute pure distilled water of which it requires 27.648 cu. in. to weigh one pound, the consumption per I. H. P. per hour will be considerably less; as, for instance, 23,760,000 ÷ 27.648 = 859,375 lbs., which would be the rate per hour of the water driven engine if the M. E. P. of the water was one pound per square inch and if the M. E. P. was increased to 20 lbs.; then twenty times more power would be developed with the same volume of water, but the weight of water consumed per H. P. per hour would be proportionately less. Now if the engine is driven by steam it will consume just as much less water in proportion as the water required to make the steam is less in volume than the steam used. Therefore if the above constant number, 859,375, be divided by the M. E. P. of any diagram and by the volume of the terminal pressure, the quotient will be the water (or steam) consumption per I. H. P. per hour.

Referring to Table 10, the numbers in the W columns are the quotients obtained by dividing the constant, 859,375, by the volumes of the absolute pressures given in the columns under T. P. and which represent terminal pressures. The table is considerably abridged

from the original, which was very full and complete, the pressures advancing by tenths of a pound from 3 lbs. to 60 lbs.; but it is seldom that in ordinary practice there is needed such accuracy. If at any time, however, a diagram should show a terminal pressure not given in the table, the correct factor for that pressure can be easily found by dividing the constant 859,375, by the relative volume of the pressure as found in Table 5 of the properties of saturated steam given in another chapter.

Referring again to Fig. 74, it is seen that the terminal pressure is 21 lbs. absolute, and by reference to Table 10 and glancing down column T. P. until 21 is reached, it will be seen that the number opposite in column W is 732.69. This number divided by the M. E. P. of the diagram Fig. 74, which is 32.4 lbs., gives 22.6 lbs. per I. H. P. per hour as the steam consumption. The rate thus found makes no allowance for clearance and compression, however, and these two very important items will be treated in a succeeding chapter together with the method of correction for the above, viz., clearance and compression, as they enter largely into the steam economy of an engine.

Questions

1. What effect has back pressure upon the work of an engine?
2. Name some of the causes of wire drawing of the steam.
3. What relation should the steam line of an indicator diagram bear to the atmospheric line?
4. What is the effect of insufficient lead upon the admission line of a diagram?

5. How does an unequal cut off affect the working of an engine?

6. How is the number of expansions in a compound engine ascertained?

7. What is the rule for finding the initial pressure by calculation?

8. Give the rule for finding the mean forward pressure.

9. When the M. F. P. is known, how may the mean effective pressure be found?

10. How should the steam be distributed in the cylinders of a compound engine?

11. What is the rule for finding the horse power developed by an engine?

12. What is meant by the steam consumption of an engine?

13. What is considered an economical rate of steam consumption for a non-condensing engine?

14. What is a fairly good rate of steam consumption for a condensing engine?

CHAPTER X

DIAGRAM ANALYSIS—*CONTINUED*

Diagram analysis continued—Corliss Centennial engine and diagrams from it—Calculating steam consumption from indicator diagrams—Clearance and compression, and how to correct a diagram for the same—How to estimate the theoretical clearance from a diagram—Measuring the volume of the clearance space with water—The theoretical expansion curve—Illustration of hyperbolic law in its application to the expansion of gases—The adiabatic curve and how to draw it—Power calculations—Method of finding the M. E. P. of a diagram—The planimeter and how to use it.

Figs. 75 to 77 are reproductions of diagrams taken by the author from the once famous engine built by Geo. H. Corliss for the Centennial Exposition which was held at Philadelphia in 1876. A brief description of this engine may not be out of place here, as it will enable the reader to study the diagrams to a better advantage.

This engine is, in fact, two simple condensing beam engines, exactly alike in every detail, standing vertical side by side and connected to a common crank shaft by means of the working beams overhead which are pivoted at their centers to the A frame of the engine. The cylinders are 40 in. bore by 10 ft. stroke and the engine runs at a speed of 36 R. P. M., thus giving a piston speed of 720 ft. per minute. The valve gear is of the regular corliss type adapted to a vertical engine, and motion is transmitted from the eccentric through the medium of a rock shaft placed horizontally on the frame. The steam and exhaust valves are

located in the cylinder heads, thereby reducing the clearance to 1.5 per cent. Each engine has its own jet condenser and air pump, which latter is of the regular bucket plunger type and receives its motion from the overhead beam through long connecting rods. The crank shaft is 18 in. in diameter and carries a gear fly-wheel 30 ft. in diameter, weighing 56 tons, the teeth of which mesh into another gear wheel 10 ft. in diameter carried on the jack shaft through which the power is transmitted to the various departments of the works. The face of the rim of the gear wheel is 24 in.

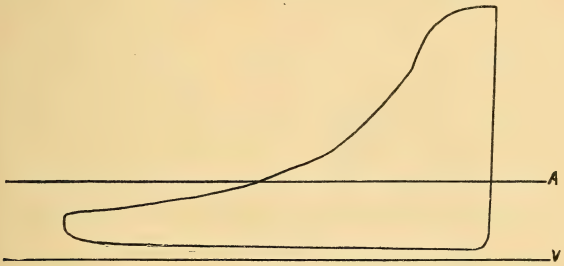


FIGURE 75

in width, which allows the length of the teeth to be 24 in., while the pitch, or distance from center to center of the teeth, is 5 in. The steam pipe is 18 in. inside diameter and the cylinders are jacketed with live steam.

This engine showed remarkable economy in the use of steam when working at or near the capacity for which it was designed by Mr. Corliss, which was 1,400 horse power. At the time Fig. 75 was taken the load was 1,122 horse power and the boiler pressure was 32.5 lbs. gauge, or 47.5 lbs. absolute. The spring used was

a No. 20, although a much better appearing diagram would have been obtained by using a No. 30 spring.

The diagram shows very slight compression, but the lead is correct. The point of cut off is not so clearly defined as it should be, and the author attributes the cause of this to the spring being too weak for the reason that when Fig. 76 was taken some eight months later from the same end of the same cylinder, but with a spring of the proper tension for the pressure, the point of cut off is much more plainly defined. (See Fig. 76.)

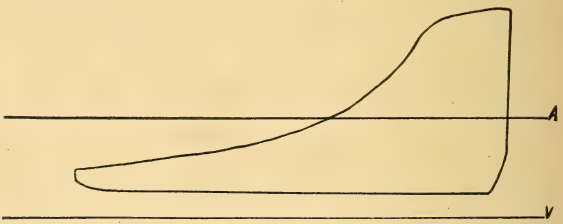


FIGURE 76.

The absolute initial pressure, as shown by Fig. 75, was 47.5 lbs., and the absolute terminal pressure was 8.5 lbs. The ratio of expansion would therefore be $47.5 \div 8.5 = 5.6$. The steam consumption per I. H. P. per hour was 14 lbs.

Fig. 77 is from the same engine, and is here introduced for the purpose of showing the great advantage resulting from a good vacuum. In fact the largest portion of the work in this case was done through the help of the vacuum, as indicated by much the largest portion of the area of the diagram being below the line of atmospheric pressure. The diagram would appear to be a kind of connecting link between the

times of Watt and Newcomen, when the vacuum did all the work, and these modern times of high steam pressure.

The circumstances under which Fig. 77 was obtained were as follows: At certain times it became necessary to run a part of the shops overtime, and the load at such times being light, the boiler pressure was allowed to drop to the point at which the engine would run the most quietly, and that point was found to be about 7 lbs. gauge pressure. A No. 10 spring was used. The horse power developed was 227.5, which multiplied by

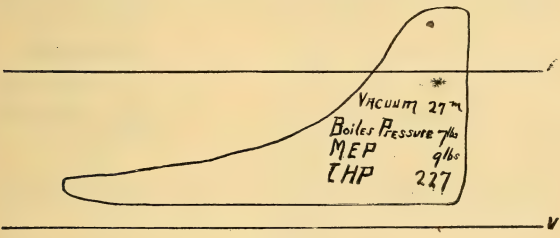


FIGURE 77.

2, as there were two engines, would equal 455 I. H. P. But the rate of steam consumption, which was 23.3 lbs. per I. H. P. per hour, was considerably higher than it was with the ordinary load, as when Fig. 75 was taken, showing that it is very poor economy to run an engine very much below its rated capacity.

Fig. 78 is from a Hamilton corliss non-condensing engine 32⅝ in. bore by 72 in. stroke. A No. 60 spring was used, the boiler pressure being 85 lbs. gauge. The I. H. P. was 652.2 and the steam consumption per I. H. P. per hour was 22.9 lbs.

There are but few points about the diagram that are open to criticism. The compression is rather high for so large an engine and the steam lines should be maintained more nearly horizontal up to the point of cut off.

Steam Consumption from Indicator Diagrams. In calculating the steam consumption of an engine, two very important factors must not be lost sight of, viz., clearance and compression. Especially is this the case in regard to clearance when there is little or no compression, for the reason that the steam required to fill the clearance space at each stroke of the engine is prac-

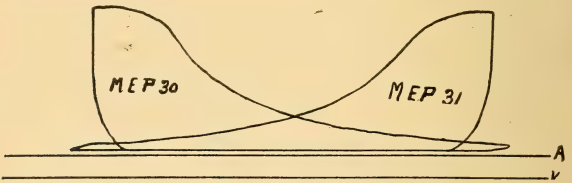


FIGURE 78.

tically wasted, and all of it passes into the atmosphere or the condensor, as the case may be, without having done any useful work except to merely fill the space devoted to clearance. On the other hand, if the exhaust valve is closed before the piston completes the return stroke, the steam then remaining in the cylinder will be compressed into the clearance space and can be deducted from the total volume which, without compression, would have been exhausted at the terminal pressure.

Figs. 79 and 80, which are reproductions of diagrams taken by the author while adjusting the valves on a 16×42 in. corliss engine, will serve to graphically

illustrate this point. Fig. 79, which was the first one to be taken, shows no compression. The point of admission at A is plainly defined by the square corner at the extreme end of the stroke. The clearance of

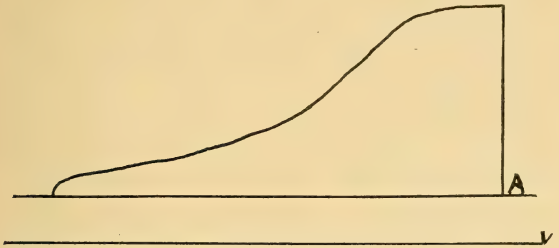


FIGURE 79.

this engine is 4 per cent. of the volume of the piston displacement. The engine being 16 in. bore by 42 in. stroke, the piston displacement is found by the following calculation: Area of piston, 201.06 sq. in. × stroke,

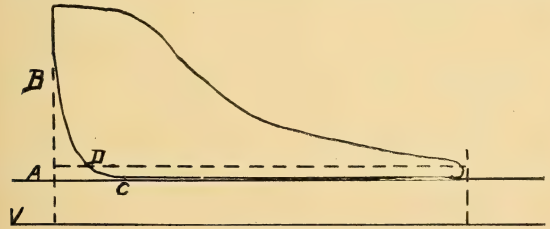


FIGURE 80.

42 in. = 8444.52 cu. in. The volume of clearance space is equal to 8444.52 cu. in. × .04 = 337.78 cu. in., which divided by 1,728 = .195 cu. ft.

By reference to Fig. 80, taken after adjusting the

valves for compression, it will be noticed that the steam is there compressed to 37 lbs., the compression curve beginning at C and ending at B. There is therefore compressed during each stroke a volume of steam equal to .195 cu. ft. at a pressure of 37 lbs. gauge, or 52 lbs. absolute.

One cubic foot of steam at 52 lbs. absolute pressure weighs .1243 lbs., and .195 cu. ft. will weigh .1243 × .195 = .0242 lbs.

The engine was running at 70 R. P. M., or 140 strokes per minute. Thus, according to Fig. 80, the total weight of steam compressed and doing useful work during one hour, and which without compression would have passed out through the exhaust pipe, is equal to .0242 × 140 × 60 = 203.28 lbs.

Now in order to estimate the steam consumption of the above engine from diagram Fig. 79, it would be necessary to account for all the steam occupying not only the volume of the piston displacement at the end of the stroke, but the clearance as well, for the reason, as before stated, that it would all be released before exhaust closure. This would equal 8444.52 cu. in. + 337.78 cu. in = 8782.3 cu. in., which divided by 1,728 = 5.08 cu. ft. each stroke, or 10.16 cu. ft. each revolution.

The absolute terminal pressure of Fig. 79 is 20 lbs. One cubic foot of steam at this pressure weighs .0507 lbs., and the weight of steam consumed each revolution would therefore be 10.16 × .0507 = .515 lbs., which multiplied by 70 R. P. M. = 36.05 lbs. per minute, or 2,163 lbs. per hour. The horse power developed by the engine at the time was 80. Therefore the steam consumption per I. H. P. per hour = 2,163 ÷ 80 = 27 lbs.

Referring again to Fig. 80 it will be remembered that the total weight of steam compressed during one hour was 203.28 lbs. The weight of steam consumed per hour, therefore, equals $2,163 - 203.28 = 1959.7$ lbs.

Owing to compression, the work area of Fig. 80 is somewhat smaller than that of Fig. 79, amounting in fact to the area of the irregular figure enclosed between the points A, B and C. The work represented by this figure amounts to a very small proportion of the total work indicated by Fig. 79, still in order to arrive at correct conclusions, it should be deducted therefrom.

Assuming the negative work to be equal to .55 horse power, we have $80 - .55 = 79.45$ I. H. P. as the work represented by Fig. 80. As the total weight of steam consumed in one hour was 1959.7 lbs., the steam consumption per I. H. P. per hour will be $1959.7 \div 79.45 = 24.67$ lbs., a saving by compression of 2.33 lbs. per H. P. per hour, besides the great advantage of having a cushion of steam in contact with the piston at the termination of the stroke, thus bringing the moving parts of the engine to rest quietly without shock or jar.

The steam consumption may also be computed from the diagram, regardless of the dimensions of the cylinder or the horse power developed. The mean effective pressure and also the absolute terminal pressure must, however, be known. This method was referred to in the preceding chapter, but in the computation therein made no correction was made for clearance and compression.

Having reviewed these two factors at considerable length it will now be in order to more fully explain the methods of treating diagrams when it is desired to make these corrections.

First, draw vertical lines C and D, Fig. 81, at each end of the diagram, and perpendicular to the atmospheric line. Draw line V, representing perfect vacuum, 14.7 lbs. below the atmospheric line, as indicated on the scale adapted to the diagram, which in this case is 50 lbs. to the inch. Continue the expansion from R, where release begins, until it intersects line D V, from which point the absolute terminal pressure can be measured.

Having ascertained the terminal pressure, which for Fig. 81 is 30 lbs., draw line D E, which may be called

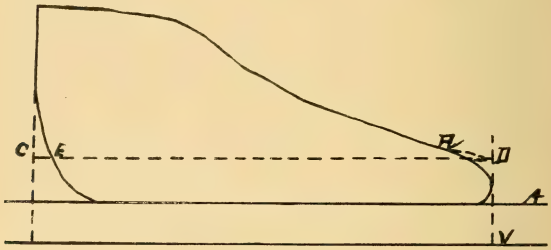


FIGURE 81.

the consumption line for 30 lbs. The terminal being 30 lbs., refer to Table 10 and find in column W, opposite 30 in column T. P., the number 1,024.5. Divide this number by the M. E. P which in Fig. 81 is 41 lbs., and the quotient, which is 24.99 lbs., is the uncorrected rate of steam consumption. This rate stands for the total consumption throughout the whole stroke represented on the diagram by the distance from D to C, which measures 3.25 in., but it is evident that there is a small portion of the return stroke, that indicated by the distance from E to C, during which

the steam compressed in the clearance space should not be charged to the consumption rate, but should be deducted therefrom. In order to do this, multiply the uncorrected rate by the distance from D to E, which is 3⅛ in, or 3.125 in., and divide the product by the distance from D to C, 3¼ in., or 3.25 in. Thus, $24.99 \times 3.125 \div 3.25 = 24.03$ lbs., which is the corrected rate and represents a saving by compression of $24.99 - 24.03 = .96$ lbs., or nearly 3.7 per cent.

In many cases the terminal pressure greatly exceeds the compression, an illustration of which is given in Fig. 82 which is a reproduction of a diagram from an

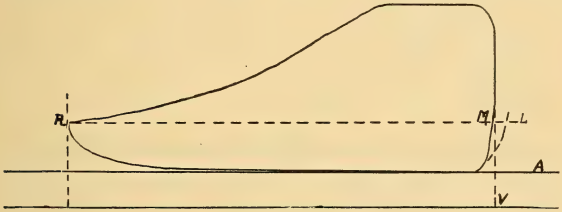


FIGURE 82.

old Wheelock engine. It now becomes necessary to extend the compression curve to L, a point equidistant from the vacuum line with the terminal at R. The consumption line R. L. now becomes longer than the stroke line R. M., therefore the corrected rate will exceed the uncorrected rate by just so much; as for instance, terminal pressure = 34 lbs. The factor, as per Table 10, = 1152.26, and the M. E. P. of the diagram is 47 lbs. Then, $1,152.26 \div 47 = 24.5$ lbs., uncorrected rate; 24.5×3.125 in. (distance R. L.) $\div 3$ in. (distance R. M.) = 25.52 lbs., corrected rate, a loss of a little more than one pound, or about 4 per cent.

There is another class of diagrams very frequently encountered in which the terminal pressure is considerably below the compression curve, and in order to compute the consumption rate by the above method it becomes necessary to continue the compression curve downwards until it meets the terminal, as illustrated at A, Fig. 83, which is a friction diagram from a Buckeye engine. R is the point of release, D A represents the consumption line, and D C the stroke. The terminal

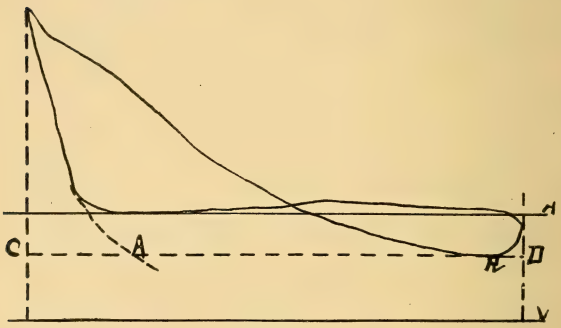


FIGURE 83.

is 8.5 lbs., and the factor for that pressure, according to Table 10, is 312.8. Dividing this number by the M. E. P., which was 7 lbs., gives 44.6 lbs. as the uncorrected rate. The distance D to A, where the compression curve intersects the consumption line, is 2.625 in., and the total length of the diagram C to D is 3.375 in. Then $44.6 \times 2.625 \div 3.375 = 35$ lbs. as the corrected rate. The extremely high rate is owing to the fact that the engine was running light, no load except a line of empty shafting.

Theoretical Clearance. The expansion and compression curves of a diagram are created by the expansion and compression of all the steam admitted during the stroke. This includes the steam in the clearance space as well as in the cylinder proper. It is evident, therefore, that the volume of the clearance is one of the factors controlling the form of these curves, and when the clearance is known a correct expansion or isothermal curve may be theoretically constructed, as will be explained later on. Also if the actual curves, either expansion or compression, of a diagram assume an approximately correct form, the clearance, if not already known, may be determined theoretically from them; although too much confidence should not be put in the results as they are liable to show either too little or too much clearance, generally the latter, especially if figured from the compression curve.

For the benefit of those who may desire to test this method of ascertaining the percentage of clearance of their engines, several illustrations will be given of its application to actual diagrams taken from engines in which the clearance was known.

Fig. 84 is from an engine in which the clearance was known to be 5 per cent. As compression cuts but a very small figure in this diagram, the expansion curve alone will be utilized for obtaining the theoretical clearance, and the process is as follows:

Select two points, C and R, in the curve as far apart as possible, but be sure that they are each within the limits of the true curve. Thus C is located just after cut off takes place, and R is at a point just before release begins. From C draw line C D parallel with the atmospheric line. From D draw line D R, and from C draw line C E, both perpendicular to the

atmospheric line. Then from R draw line R E, forming a rectangular parallelogram, C D R E, with two opposite corners, C and R, within the curve. Now through the other two corners, D and E, draw the diagonal D E, extending it downwards until it intersects the vacuum line V. From this point erect the vertical line V W, which is the theoretical clearance line.

To prove the result proceed as follows: Measure the length of diagram from F to G, which in this case

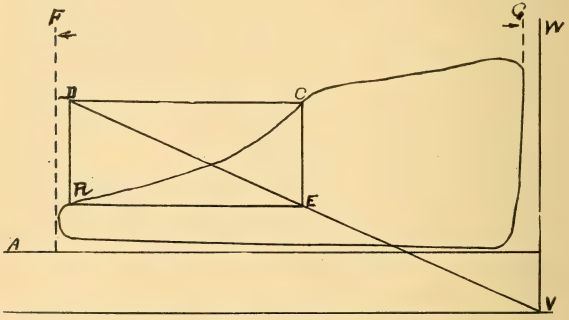


FIGURE 84.

is 3.75 in., representing piston displacement. Next measure the distance from F to the clearance line V W, which is 3.91 in., representing piston displacement with volume of clearance added. Then $3.91 - 3.75 = .16$, which represents volume of clearance; and $.16 \times 100 \div 3.75 = 4.3$ per cent., which is approximately near the actual clearance, which, as before stated, was 5 per cent.

Fig. 85 serves to illustrate the same method applied to the compression curve. This diagram is a repro-

duction of one taken from the low pressure cylinder of a large compound condensing corliss engine in which the actual clearance was 2.25 per cent. Two points, G and H, are selected in the compression curve, and from them the parallelogram G H I K is erected with two of its opposite corners, G and H, well within the limits of the curve, while through the other two corners, I and K, the diagonal I K C is drawn intersecting the vacuum line at C, thus locating the

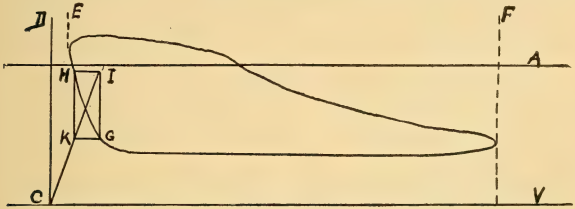


FIGURE 85.

point from which the clearance line C D can be drawn. The measurements in this case are as follows:

Total length of diagram, E to F = 3.75 in.

Distance from clearance line, D C, to F = 3.875 in.

Volume of clearance = 3.875 − 3.75 = .125 in.

.125 × 100 ÷ 3.75 = 3.33 per cent. clearance, which is 1.08 per cent. more than the known clearance.

However, notwithstanding the liability to error in many cases, still this method of computing clearance may often be utilized to good advantage.

Another and more practical method of measuring clearance is as follows: Place the engine on the dead center. Remove the valve chest cover and take out the valve. Close the cylinder cock on that end of the cylinder to which the piston has been moved, leaving

the cock on the opposite end of the cylinder open and disconnected from its drip pipe, so as to give an opportunity for catching any water that may leak past the piston while measuring the clearance space. Then having first provided a known weight of water, always making sure of having a little more than enough, pour it into the steam port until the clearance space is filled to a level with the valve seat. When this is done, weigh the water that is left and deduct it from the original quantity, and the remainder will be the number of pounds of water required to fill the clearance, from which it is an easy matter to compute the number of cubic inches or cubic feet in the space devoted to clearance. If any water leaks past the piston during the operation it should be weighed and deducted from the total quantity poured into the port.

In the case of an engine having the valve chest on the side of the cylinder it will be necessary to close the steam port either by blocking the valve against it or by fitting a piece of soft wood into it, making it water tight. The water can then be poured into the clearance space through a pipe connected to the indicator opening in that end of the cylinder. Care should be exercised to allow a vent for the air to escape as it is displaced by the water.

The Theoretical Expansion Curve. According to Boyle's law the volume of all elastic gases is inversely as their pressures, and steam being a gas conforms substantially to this law; although the expansion curves of indicator diagrams are affected more or less by the loss of heat transmitted through the cylinder walls, and by the change in the temperature of the steam produced by the changes in pressure during the progress of the stroke. The pressure generally falls more

rapidly during the first part of the stroke, and less rapidly during the last portion than it should in order to conform strictly to the above law, and the terminal pressure usually is greater than it should be to agree with the ratio of expansion. But this fullness of the expansion curve of the diagram near the end compensates in a measure for the too rapid fall near the beginning of the stroke. Therefore, if the engine is in fairly good condition with the valves properly adjusted and not leaking, and the piston rings are steam tight,

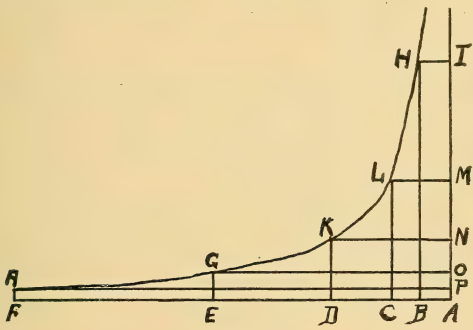


FIGURE 86.

it may be assumed that the expansion of the steam in the cylinder takes place according to Boyle's law and it is found that the expansion curve drawn by the indicator practically coincides with a hyperbolic curve constructed according to that law.

Fig. 86 graphically illustrates the application of the hyperbolic law to the expansion of gases. The horizontal lines represent volumes and the vertical lines represent pressures. The base line, A F, represents the full stroke of a piston in the cylinder of an engine,

and the vertical line A I represents the pressure of the steam at the commencement of the stroke.

Suppose there is no clearance and that the steam has been admitted up to point H when it is cut off. The rectangle A B H I is the product of the pressure multiplied by the volume of the steam thus admitted. When the piston has traveled from A to C the volume of the steam has been doubled and the pressure C L has been reduced to just one-half what it was at A I, but the area of the rectangle A C L M is equal to the area of the initial rectangle, and, as before, is the product of the pressure C L multiplied by the volume A C. As the piston travels still farther, as from A to D, the steam is expanded to four volumes while the pressure at D K will only be one-fourth that of the initial pressure; but the new rectangle A D K N is still equal in area to either of the others, A B H I or A C L M.

The same law applies to each of the remaining rectangles; A E G O representing five volumes and one-fifth of the initial pressure, and A F R P representing six times the initial volume and one-sixth of the initial pressure, but each having the same area as the initial rectangle A B H I. Now the area of the rectangle A B H I represents the work done by the steam up to the point of cut off, and the area of the hyperbolic figure enclosed by the lines B H R F represents the work done by the expansion of the steam after cut off occurs. This area and the amount of work it represents may be computed by means of the known relations of hyperbolic surfaces with their base lines; as for instance, if the base lines A B, A C, A D, etc., extend in geometrical ratio, as 1, 2, 4, 8, 16, etc., the successive areas, B H L C, B H K D, B H G E, etc., increase in arithmetical ratio, as 1, 2, 3, 4, etc.

On the principles of common logarithms, which represent in arithmetical ratio natural numbers in geometrical ratio, tables of hyperbolic logarithms have been computed for the purpose of facilitating the calculation of areas of work due to different degrees of expansion. Such a table is given elsewhere in this book, and in Chapter IX is described the method of calculating the M. E. P. by this means.

A theoretical curve may be constructed conjointly with the actual expansion curve of a diagram by first locating the clearance and vacuum lines and then pur-

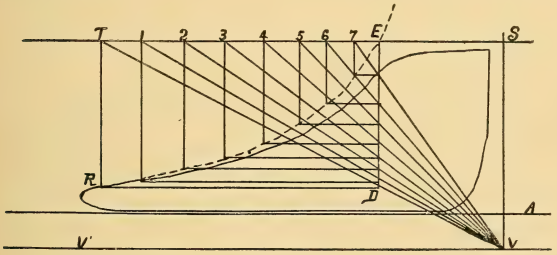


FIGURE 87.

suing the method illustrated by Fig. 87. A curve so produced is called an isothermal curve, meaning a curve of the same temperature.

Referring to Fig. 87, suppose, first, that it is desired to ascertain how near the expansion curve of the diagram coincides with the isothermal curve, at or near the point of cut off. Select point R near where release begins, but still well within the expansion curve. From this point draw the vertical line, R T, parallel with the clearance line, V S. Then draw the horizontal line, S T, parallel with the atmospheric line,

and at such a height above it as will equal the boiler pressure as measured by the scale adapted to the diagram; such measurement to be made from the atmospheric line to correspond with the gauge pressure. From T draw the diagonal T V, and from R draw the horizontal line R D parallel with the atmospheric line. From D, where this line intersects T V, erect the perpendicular D E, thus forming the parallelogram R D E T, and as line T V passes through two of its opposite angles and meets the junction of the clearance and vacuum lines, the other two angles, R and E, will be in the theoretical curve, and R being the starting point, it is obvious that this curve must pass through E, which would be the theoretical point of cut off on the steam line S T.

Two important points in the theoretical curve have now been located, viz., E as the cut off, and R as the point of release. In order to obtain intermediate points, draw any desired number of lines downward from points in S T, as 1, 2, 3, 4, 5, etc., and continue them downwards far enough to be sure that they will meet the intended curve, and from the same points in S T draw diagonals 1 V, 2 V, 3 V, 4 V, 5 V, etc., all to converge accurately at V. From the intersection of these diagonals with D E draw horizontal lines parallel with V V′, and the points of junction of these lines with the vertical lines will be points in the theoretical curve. It will now be an easy matter to trace the curve through these points. If, on the other hand, it be desired to compare the curves toward the exhaust end of the diagram, draw lines E D and E T, Fig. 88, also T R, locating R near where release commences, after which draw line R D, completing the parallelogram E T R D, fixing R as a point in the theoretical

curve started at E. After drawing the diagonal T V, proceed in the same manner as before to locate the intermediate points.

It will be observed that in order to ascertain the performance of the steam near the beginning of the stroke, the starting point of the isothermal curve must be near the point of release, and conversely, if the starting point of the curve is located near the point of cut off and coincident with the actual curve, the test will apply towards the end of the stroke. It is not to be expected that the expansion curve of any diagram taken in practice will conform strictly to the lines of

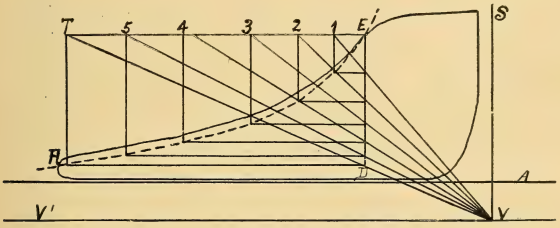


FIGURE 88.

the isothermal curve, especially towards the latter end of the stroke, owing to the reëvaporation of water resulting from the condensation of steam which was retained in the cylinder by the closing of the exhaust valve. This reëvaporation commences just as soon as the temperature of the steam, owing to reduction of pressure due to expansion, falls below the temperature of the cylinder walls, and it continues at an increasing rate until release occurs. The tendency of this reëvaporation or generation of steam within the cylinder during the latter portion of the stroke is to

raise the terminal pressure considerably above what it would be if true isothermal expansion took place. The terminal pressure may also be augmented by a leaky steam valve, while, on the other hand a leaky piston would cause a lowering of the terminal and an increase in the back pressure.

The Adiabatic Curve. If it were possible to so protect or insulate the cylinder of a steam engine that there would be absolutely no transmission of heat either to or from the steam during expansion, a true adiabatic curve or "curve of no transmission" might

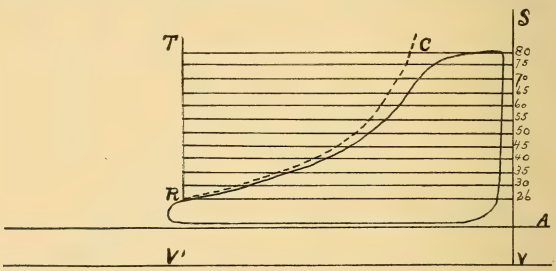


FIGURE 89.

be obtained. The closer the actual expansion curve of a diagram conforms to such a curve, the higher will be the efficiency of the engine as a machine for converting heat into work.

Fig. 89 illustrates a method of figuring a curve which, while not strictly adiabatic, will be near enough for all practical purposes, while at the same time it will give the student an opportunity to study the laws governing the expansion of saturated steam.

To draw the curve, first locate the clearance and vacuum lines V S and V V'. Next locate point R in

the expansion curve near where release begins, making this the starting point, and also the point of coincidence of the expansion curve with the adiabatic curve. The other points in the curve are located from the volumes of steam at different pressures during expansion; the pressures being measured from the line of perfect vacuum, and the volumes from the clearance line.

The absolute pressure at R, Fig. 89, is 26 lbs. From point R erect the perpendicular R T. Also draw horizontal line R 26 parallel with the vacuum line and at a height equal to 26 lbs. above vacuum line V V', as shown by the scale, which in this case was 40. The length of line R 26, measured from R to the clearance line, is $3\frac{1}{16}$ in., or 3.0625 in. By reference to Table 5 it will be seen that the volume of steam at 26 lbs. absolute, as compared with water at 39°, is 962. Now if the length of line R 26 be divided by this volume, and the quotient multiplied by each of the volumes of the other pressures represented at points 30, 35, 40, 45, etc., up to the initial pressure, the products will be the respective distances from the clearance line of points in the adiabatic curve. These points can be marked on the horizontal lines drawn from the clearance line to line R T.

Starting with line R 26, it has been noted that its length is 3.0625 in., and that the volume was 962. $3.0625 \div 962 = .003$. Then the volume of steam at 30 lbs. is 841, which being multiplied by $.003 = 2.5$ in., the length of line 30. Next the volume at 35 lbs. = 728. Multiplying this volume by $.003 = 2.1$ in., length of line 35, and so in like manner for each of the other points.

The process involves considerable figuring and care-

ful and accurate measurements, which should be made with a steel rule with decimal graduations. It is not expected that the cut Fig. 89 will be found accurate enough in its measurements to serve as a standard; it being intended only to serve as an illustration of the process. The diagram from which the illustration was drawn was taken from a 600 H. P. engine situated some 200 ft. from the boilers, and there was a considerable cooling of the steam by the time it reached the engine, the effect of which is apparent. The curve produced by the measurements is shown by the broken line. The process can be applied to any diagram.

Power Calculations. The area of the piston (minus one-half the area of rod) multiplied by the M. E. P., as shown by the diagram, and this product multiplied by the number of feet traveled by the piston per minute (piston speed) will give the number of foot pounds of work done by the engine each minute, and if this product be divided by 33,000, the quotient will be the indicated horse power (I. H. P.) developed by the engine.

Therefore one of the first requisites in power calculations is to ascertain the M. E. P. Beginning with the most simple, though only approximately correct, method of obtaining the average pressure, as illustrated by Fig. 90, draw line A B touching at A and cutting the diagram in such manner that the space D above it will equal in area spaces C and E taken together, as nearly as can be estimated by the eye. Then with the scale measure the pressure along the line F G at the middle of the diagram, which will be the M. E. P.

The process is based upon the theory that the

average width of any tapering figure is its width at the middle of its length. This method should not be relied upon as accurate, but is convenient at times when it is desired to make a rough estimate of the horse power of an engine.

Figuring the M. E. P. by Ordinates. This is a very common method and one which can be relied upon to give accurate results, provided care is exercised in its use.

The process consists in drawing any convenient

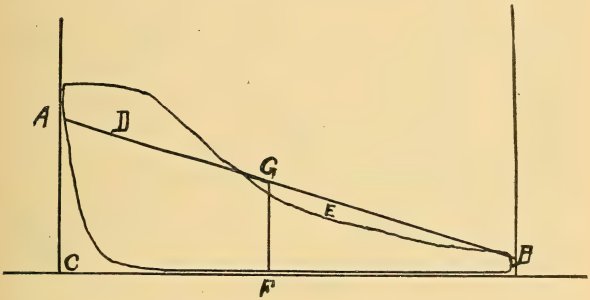


FIGURE 90.

number of vertical lines perpendicular to the atmospheric line across the face of the diagram, spacing them equally, with the exception of the two end spaces, which should be one-half the width of the others, for the reason that the ordinates stand for the centers of equal spaces, as for instance, line 1, Fig. 91, stands for that portion of the diagram from the end to the middle of the space between it and line 2. Again, line 2 stands for the remaining half of the second space and the first half of the third, and so on. This

is an important matter, and should be thoroughly understood, because if the spaces are all made of equal width, and measurements are taken on the ordinates, the results will be incorrect, especially in the case of high initial pressure and early cut off, following which the steam undergoes great changes.

If the spaces are all made equal, the measurements will require to be taken in the middle of them, and errors are liable to occur, whereas if spaced as before described, the measurements can be made on the

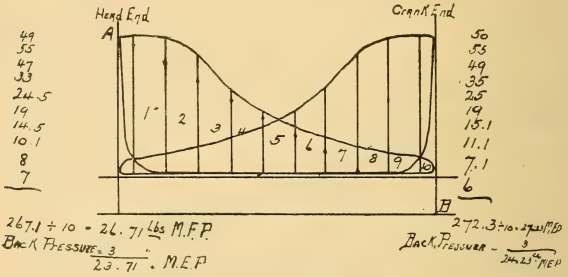


FIGURE 91.

ordinates, which is much more convenient and will insure correct results. Any number of ordinates can be drawn, but ten is the most convenient and is amply sufficient, except in case the diagram is excessively long. For spacing the ordinates, dividers may be used, or a parallel ruler may be procured from the makers of the indicator; but one of the most convenient and easily procurable instruments for this purpose is a common two-foot rule, and the method of using it is illustrated in Fig. 91.

First draw vertical lines at each end of the diagram,

perpendicular to the atmospheric line and extending downwards to the vacuum line, or below it if necessary, in order to have a point on which to lay the rule. In Fig. 91 points A and B are found to be the most convenient. Now lay the rule diagonally across the diagram, touching at A and B, and the distance will be found to be 3¾ in., or 60 sixteenths.

Suppose it be desired to draw 10 ordinates. Divide 60 by 10, which will give 6 sixteenths, or ⅜ in. as the width of the spaces, but as the two end spaces are to be one-half the width of the others, there will be 11 spaces altogether, the two outer ones having a width equal to one-half of ⅜ or $\frac{3}{16}$. Now apply the rule again in the same manner, touching at points A and B, and with a sharp pointed pencil begin at A and mark the location of the first ordinate according to the rule, at a distance of $\frac{3}{16}$ from the end. Then ⅜ from this mark make another one, which will locate the second ordinate, and proceed in like manner to locate the others. The last two or three marks generally come below the diagram, and if the diagram be taken from a condensing engine it may be necessary to tack it on to a larger sheet of paper in order to get these points. Having correctly located the ordinates, they may now be drawn perpendicular to the atmospheric line or vacuum line, either of which will answer.

It should be noted that, owing to the diagonal position of the rule with relation to the atmospheric line, the spaces are not of the actual width as described by the rule, but this is unimportant, so long as they are of a uniform width. This method can be applied to any diagram, no matter what its length may be, and point B may be located at any distance below the atmospheric or vacuum lines, wherever it is the most con-

venient for the subdivisions on the rule, sixteenths, eighths, etc., so long as it is in line with the end of the diagram. Having thus drawn the ordinates, the M. E. P. may be found by measuring the pressure expressed by each one, using for this purpose the scale adapted to the spring used, adding all together and dividing by the number of ordinates which will give the average pressure.

Referring to Fig. 91, begin with ordinate No. 1 on the diagram, from the head end of the cylinder. In this case a 40 spring was used. Lay the scale on the ordinate with the zero mark where it intersects the compression curve. The pressure is seen to be 49 lbs. Set this down at that end of the card and measure the pressure along ordinate No. 2, which is 55 lbs. Proceed in this manner to measure all the ordinates, placing the resulting figures in a column, after which add them together and divide by 10. The result is 26.71 lbs., which is the mean forward pressure (M. F. P.). To obtain the mean effective pressure, deduct the back pressure, which is represented by the distance of the exhaust line of the diagram above the atmospheric line in a non-condensing engine, and in a condensing engine the back pressure is measured from the line of perfect vacuum, 14.7 lbs., according to the scale below the atmospheric line.

In Fig. 91 the back pressure is found to be 3 lbs. Therefore the M. E. P. of the head end will be $26.71 - 3 = 23.71$ lbs. On the crank end the M. F. P. is 27.23 lbs, and $27.23 - 3 = 24.23$ lbs. = M. E. P. The average effective pressure on the piston, therefore, will be $23.71 + 24.23 \div 2 = 23.97$ lbs.

Unless great care is exercised in the measurements, errors are liable to occur in applying this method,

especially with scales representing high pressures, as 60, 80, etc. The most convenient and reliable method is to take a narrow strip of paper of sufficient length, and starting at one end, apply its edge to each ordinate in succession and mark their lengths on it consecutively with the point of a knife blade or a sharp pencil. Having thus marked on the paper the total length of all the ordinates, ascertain the number of inches and fractions of an inch thereon, the fractions to be expressed decimally, and divide by the number of ordinates. The quotient will be the average height of the diagram, and as the scale expresses the number of pounds pressure for each inch or fraction of an inch in height, if the average height of the diagram be multiplied by the number of the scale, the product will be the M. F. P.

Referring again to Fig. 91, if the lengths of the ordinates drawn on the head end diagram be measured, their sum will be found to be $6\frac{8}{12}$ or 6.666 in. Dividing this by 10 gives .666 in. as the average height. The mean forward pressure will then be as follows: $.666 \times 40 = 26.64$ lbs., or practically the same as found by the other method.

Fig. 92 illustrates a type of diagram frequently met with, and one which requires somewhat different treatment in estimating the power developed. It will be noticed that, owing to light load and early cut off, the expansion curve drops considerably below the atmospheric line, notwithstanding that the engine from which this diagram was taken is a non-condensing engine. When release occurs at R, and the exhaust side of the piston is exposed to the atmosphere, the pressure immediately rises to a point equal to, or slightly above, that of the atmosphere.

Fig. 92 was taken during a series of experiments made by the author for the purpose of ascertaining the friction of shafting and machinery, and the engine it was obtained from is a Buckeye 24 × 48 in. The boiler pressure at the time was only 40 lbs., and a No. 20 spring was used. The ordinates are drawn according to the method illustrated in Fig. 91. By placing the rule on points A and B, the distance between those two points is found to be 3⅝ in., or 58 sixteenths. Dividing this by 10 gives 5.8 sixteenths, or nearly 3/8

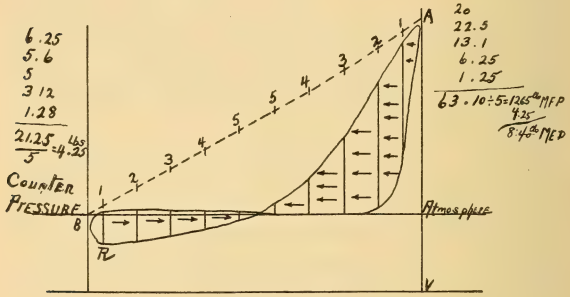
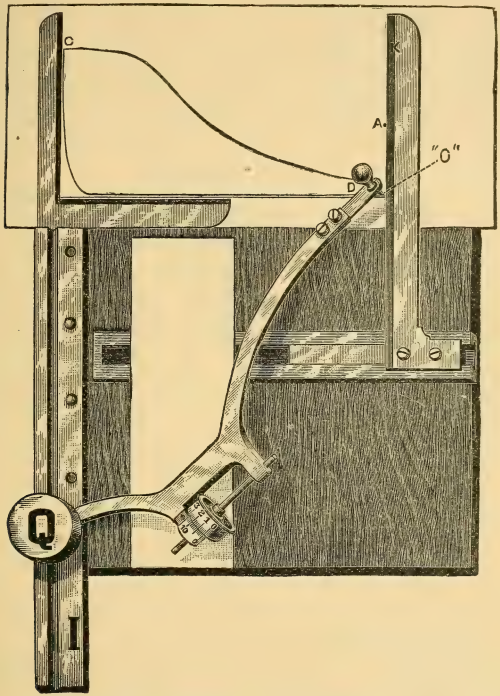


FIGURE 92.

in., as the width of the spaces; the two end spaces being one-half of this, or $\frac{3}{16}$ in. wide. The first five ordinates, counting from A, express forward pressure, represented by the arrows. The remaining five ordinates, counting from B, express counter or back pressure, represented by the arrows pointing in the opposite direction. Measuring the pressures along the first five ordinates, and adding them together, gives 63.1 lbs., which divided by 5 gives 12.65 lbs. as the mean forward pressure (M. F. P.).

Then figuring up the counter pressure in the same manner on the other five ordinates, beginning at B,



COFFIN AVERAGER OR PLANIMETER.

the result is 4.25 lbs. The M. E. P. therefore will be $12.65 - 4.25 = 8.4$ lbs.

Obtaining the M. E. P. with the Planimeter. The area of the diagram represents the actual work done by the

steam acting upon the piston. In a non-condensing engine the lower or exhaust line of the diagram must be either coincident with or slightly above the atmospheric line in order to express positive work. Any deviation of this line, either above or below the atmospheric line, represents counter pressure, the amount of which may be ascertained by measurements with the scale, and should be deducted from the mean forward pressure.

On the other hand, the exhaust line of a diagram from a condensing engine falls more or less below the atmospheric line, according to the degree of vacuum maintained, and the nearer this line approaches the line of perfect vacuum, as drawn by the scale, 14.7 lbs. below the atmospheric line, the less will be the counter pressure, which in this case is expressed by the distance the exhaust line is above that of perfect vacuum.

The prime requisite therefore in making power calculations from indicator diagrams is to obtain the average height or width of the diagram, supposing it were reduced to a plain parallelogram instead of the irregular figure which it is.

The planimeter, Fig. 93, is an instrument which will accurately measure the area of any plane surface, no matter how irregular the outline or boundary line is, and it is particularly adapted for measuring the areas of indicator diagrams, and in cases where there are many diagrams to work up, it is a very convenient instrument and saves much time and mental effort. In fact, the planimeter has of late years become an almost indispensable adjunct of the indicator. It shows at once the area of the diagram in square inches and decimal fractions of a square inch, and when the area is thus known it is an easy matter to obtain the aver-

age height by simply dividing the area in inches by the length of the diagram in inches. Having ascertained the average height of the diagram in inches or fractions of an inch the mean or average pressure is found by multiplying the height by the scale. Or the process may be made still more simple by first multiplying the area, as shown by the planimeter in square

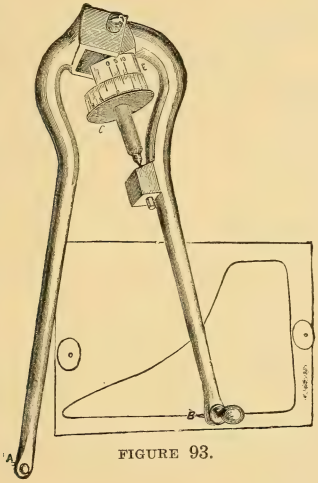


FIGURE 93.

inches and decimals of an inch, by the scale, and dividing the product by the length of the diagram in inches. The result will be the same as before, and troublesome fractions will be avoided.

Questions

1. What advantage is gained by placing the valves of a corliss engine in the cylinder head?

2. What two important factors must be considered in calculating the steam consumption of an engine?

3. What advantage, in an economical way, is gained by compression?

4. How is the piston displacement of an engine ascertained?

5. How is the steam consumption per horse power per hour calculated? (See Figs. 79 and 80.)

6. What effect does compression have upon the work area of an indicator diagram? (See Fig. 80.)

7. How can the steam consumption, as shown by the diagram, be corrected for clearance and compression? (See Figs. 81, 82 and 83.)

8. What do the expansion and compression curves of a diagram show? (See theoretical clearance.)

9. If the clearance of an engine is not known, how may it be determined theoretically from an indicator diagram? (See Figs. 84 and 85.)

10. What other method may be employed to ascertain the clearance?

11. What is Boyle's law for gases?

12. Is steam a gas?

13. What is a hyperbolic curve? (See Fig. 86.)

14. How may a theoretical curve be constructed from an indicator diagram? (See Fig. 87.)

15. What effect does reëvaporation have upon the expansion curve?

16. When does reevaporation take place within the cylinder?

17. How does a leaky steam valve affect the terminal pressure?

18. If the piston rings leak, what is the result?

19. What is an adiabatic curve, and what conditions are necessary in order to produce it?

20. What is the rule for computing the horse power developed by an engine?

21. What important factor is necessary in all power calculations?

22. How may the M. E. P. be found? (See Figs. 91 and 92.)

23. What does the area of the diagram represent?

24. In a diagram from a non-condensing engine, where should the exhaust line be?

25. If the exhaust line of a diagram is above the atmospheric line, what does it show?

26. Where should the exhaust line of a diagram from a condensing engine be?

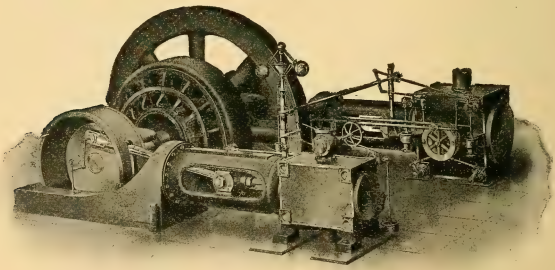
27. How is the M. E. P. ascertained by the planimeter?

CHAPTER XI

ENGINE OPERATION

Engine operation — Simple engines — Compound engines—Condensing and non-condensing engines—Condensers—Surface and jet condensers—Starting a condensing engine—Rules for estimating quantity of condensing water required—The governor—Speed regulation—How to keep a governor in good working condition—Lubrication of an engine—Running "over" or "under"—Oiling the bottom guide on horizontal engines—Oiling the crank pin and main bearings—Shaft governors—Keying up an engine—What to do with a hot pillow block—Feed water heaters—Economy of using exhaust steam for heating feed water—Changing the speed of an engine.

The following general suggestions regarding the operation of engines are made with the object in view

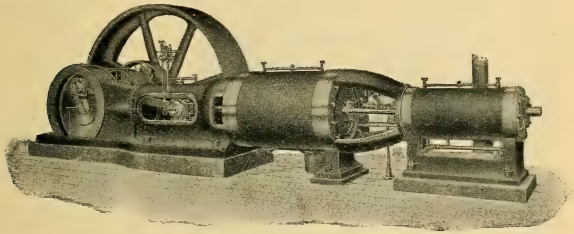


CROSS COMPOUND DIRECT CONNECTED CORLISS ENGINE, ALLIS CHALMERS CO.

of assisting young engineers or those whose experience has been limited to one or two types of engines.

In many cases a young man starts in as a fireman in

a certain plant, and by industry and a strict devotion to duty becomes able in course of time to handle not only the boilers successfully, but is at times required to run the engine in the absence of the engineer. He thus acquires the ability to operate that particular engine, while at the same time he may be comparatively ignorant of the peculiarities of other types. Or an engineer may have had years of experience with simple non-condensing engines, but if called upon to operate a compound condensing engine, he would find that he had a great deal to learn.

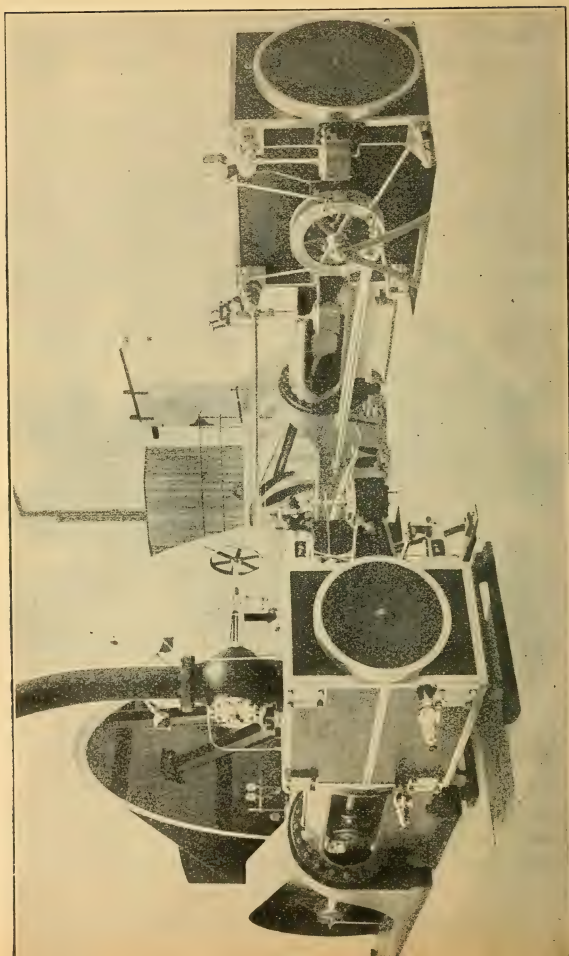


TANDEM COMPOUND ENGINE, BUCKEYE ENGINE CO.

Engines may be divided into two general classes, viz., simple and compound.

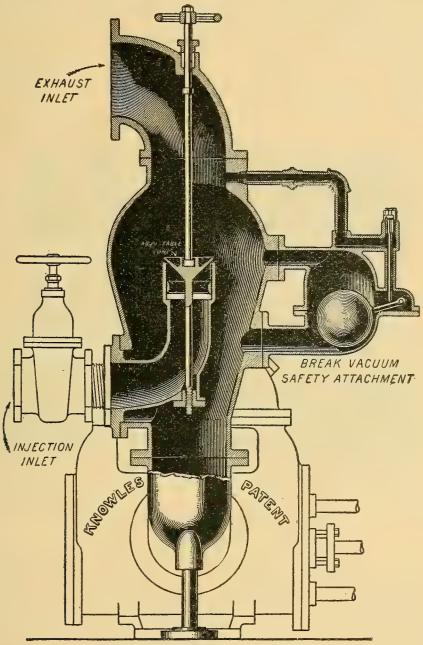
A simple engine may be either condensing or non-condensing, but its leading characteristic is, that the steam is used in but one cylinder, and from thence it is exhausted either into the atmosphere or into a condenser.

A compound engine is one in which the steam is made to do work in two or more cylinders before it is allowed to exhaust, and this class of engine may be either condensing or non-condensing.



CROSS COMPOUND HAMILTON CORLISS ENGINE.

In a non-condensing engine the pressure of the atmosphere, amounting to 14.7 lbs. per square inch at sea level, is constantly in resistance to the motion of



KNOWLES JET CONDENSER.

the piston. Therefore the exhaust pressure cannot fall below the atmospheric pressure, and is generally from two to five pounds above it, caused by the resistance of bends and turns in the exhaust pipe, or other

causes which tend to retard the free passage of the steam.

The advantage, from an economical point of view, of exhausting the steam into a condenser in which a vacuum is maintained, is fully set forth in Chapter VIII. on Definitions. (See Vacuum.)

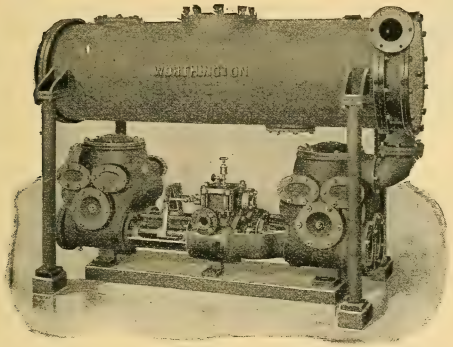
Condensers are of two classes, viz., jet condensers and surface condensers.

In a jet condenser the steam is exhausted into an air-tight iron vessel of any convenient shape, generally cylindrical and of suitable size, and is there condensed by coming in contact with a jet of cold water, admitted in the form of a spray. The air pump, which also maintains a vacuum in the condenser, draws this water, together with the condensed steam, away from the condenser.

The surface condenser, like the jet condenser, consists of an air-tight iron vessel, either cylindrical or rectangular in shape, but unlike the jet condenser, it is fitted with a large number of brass or copper tubes of small diameter, through which cold water is forced by a pump, called a circulating pump. A vacuum is also maintained in the body of the condenser by the air pump, and the steam exhausting into this is condensed by coming in contact with the cool surface of the tubes. Or, as is often the case, the exhaust steam passes through the tubes in place of around them, and the condensing water is forced into and through the body of the condenser, the vacuum in this case being maintained in the tubes. Owing to the fact that in a surface condenser the steam does not mix with the water, a larger quantity of condensing water is required than in a jet condenser, but on the other hand, an advantage is gained by having the pure water of con-

densation; in other words, the condensed steam, which may be returned to the boilers along with the regular feed water supply, and will greatly aid in preventing the formation of scale, while the water of condensation as it comes from a jet condenser, being mixed with oil and other impurities, is not, as a rule, suitable to be fed to boilers.

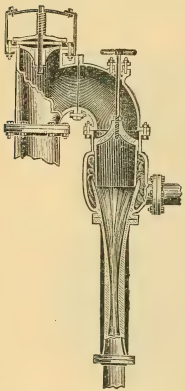
There are many different types of jet condensing



WORTHINGTON SURFACE CONDENSER, WITH AIR AND CIRCULATING PUMP.

apparatus, in some of which no air pump is used; their action being based somewhat upon the principle of the injection used for feeding boilers. In this type of jet condenser the supply of condensing water is drawn from outside pressure, either from an overhead tank or other source, and passing into an annular enlargement of the exhaust pipe, is discharged downwards in the form of a cylindrical sheet of water into a nozzle which gradually contracts. The exhaust steam, entering at the

same time, is condensed, and the contracting neck of the cone shaped nozzle gradually brings the water to a solid jet, and it rushes through the nozzle with a velocity sufficient to create a vacuum. This type of condenser can only be used where the discharge pipe has a free outlet.



SIPHON CONDENSER.

The jet condenser with air pump attached is the most reliable as well as economical for general purposes, for the reason that with this type the supply of condensing water may be drawn from a well or other source lower than the level of the condenser. These condensers are also generally fitted with a "force injection," as it is called, which is simply a connection between the condenser and water main or tank, for the purpose of letting cold water into the condenser to condense the exhaust steam when starting the engine, and thus aid in forming a vacuum. When a good vacuum has been established and the engine is running up to speed, the force injection may be shut off, and the water will flow into the condenser from the well by suction. The above refers to engines in which the air pump receives its motion directly from the engine.

Another type of jet condensing apparatus is the independent air pump and condenser, which is still better, for the reason that the air pump, which is simply an ordinary double acting steam pump, may be started independently of the engine, and, in fact,

before the engine is started, thus creating a vacuum in the condenser, and greatly facilitating the starting of the engine. Another great advantage in the independent condensing apparatus is that there is not so much danger of the water backing up into the cylinder in case of a sudden shut down of the engine, because the air pump may be kept in operation, thus relieving the condenser of water; whereas, if the air pump gets its motion from the engine, it will of course stop when the engine stops, and unless the injection water is shut off immediately after closing the throttle there is great danger of the cylinder becoming flooded with water, resulting very often in a broken cylinder head, or a bent piston rod.

The quantity of water required to condense the exhaust steam of an engine is determined by three factors: First, the density, temperature and volume of the steam to be condensed in a given time; second, the temperature of the overflow or discharge, and third, the temperature of the injection water. For instance, the temperature of the injection water may be 35° in the winter and 70° in the summer. Or it may be desired to keep the overflow at as high a temperature as possible for the purpose of feeding the boilers. Again, the pressure, and consequently the temperature of the exhaust steam as it enters the condenser, varies with different engines, and often with the same engine, according as the load is light or heavy. Therefore the only accurate method of estimating the amount of condensing water required per minute or per hour, under any and all conditions, is to first ascertain the weight of water required to condense one pound weight of steam at the temperature and pressure at which the steam is being exhausted.

In these calculations the total heat in the steam must be considered. This means not only the sensible heat, but the latent heat also.

The formula for solving the above problem may be expressed as follows: $\frac{H-T}{T-I} = W$, in which

H = total heat in the steam,

T = temperature of the overflow,

I = temperature of the injection water,

W = weight of water required to condense one pound weight of steam.

To illustrate, suppose the absolute pressure of the exhaust, as shown by the indicator diagram, is 7 lbs. Referring to Table 5, it will be seen that the total heat in steam at 7 lbs. absolute is 1135.9 heat units. Assume the temperature of the overflow to be 110°, which is as high as is consistent with a good vacuum Now the total heat to be absorbed from each pound weight of steam in this case would be 1135.9 – 110 = 1025.9 B. T. U.

Suppose the temperature of the condensing water to be 55° and the temperature of the overflow being 110°, there will be 110° – 55° = 55° of heat absorbed by each pound of water passing into and through the condenser, and the number of pounds of water required to condense one pound weight of steam under the above conditions will equal the number of times 55 is contained in 1025.9. Expressed in plain figures the calculation is $\frac{1135.9-110}{110-55} = 18.65$ lbs.

In order to ascertain the quantity of condensing water required per horse power per hour, it is only necessary to know the number of pounds weight of steam consumed by the engine per horse power per hour, as shown by the indicator diagram, and multiply

this by the weight of condensing water required per pound of steam, as found by the above solution.

Thus, suppose the steam consumption of the engine to be 17 lbs. per I. H. P. per hour. Then $17 \times 18.65 = 317.05$ lbs. per hour, which reduced to gallons = 38.2 gals.

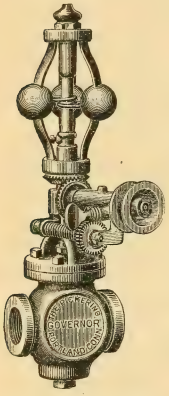
Or, if the steam consumption is not known, and the weight only of condensing water required per hour is desired, regardless of the horse power developed by the engine, it will be necessary, first, to estimate the total volume of steam exhausted per hour and calculate its weight from its known pressure.

Thus, assume the engine to be 24×48 in., and the R. P..M. to be 80. Then the piston displacement will equal area of piston less one-half area of rod multiplied by length of stroke. Referring to Table 9, the area of a circle 24 in. in diameter = 452.39 sq. in. Suppose the piston rod to be 4.5 in. in diameter, its area, according to Table 9, is 15.904 sq. in., one-half of which = 7.952 sq. in. The effective area of the piston now becomes $452.39 - 7.952 = 444.43$ sq. in., and the piston displacement equals $444.43 \times 48 = 21332.64$ cu. in. Dividing this by 1728 (number of cubic inches in a cubic foot) gives 12.34 cu. ft. of piston displacement. The total volume of steam exhausted per minute, therefore, will be $12.34 \times 2 \times 80 = 1974.4$ cu. ft.

The absolute pressure of the exhaust may again be assumed to be 7 lbs. per square inch. Referring to Table 5, the weight of one cubic foot of steam at 7 lbs. absolute is .0189 lbs., and the total weight of steam exhausted per minute, therefore, would be $1974.4 \times .0189 = 37.3$ lbs., and if 18.65 lbs. water is required to condense one pound of steam, the quantity required per minute would be $37.3 \times 18.65 = 695.8$ lbs., or per

hour, 41748 lbs., equal to 5029 gals. This is at the rate of 8.7 lbs., or a little more than one gallon per revolution for a 24 × 48 in. simple condensing engine.

The Governor. The proper regulation of speed is a very important point in the operation of engines, and in order to attain this most desirable object, due attention must be paid to the governor. If it be a throttling governor (see Chapter VIII, on Definitions), care should be taken to not pack the small valve stem too tight, nor allow the packing to become hard from long usage. The packing nut should be left loose enough to allow a slight leakage of steam past the stem. This will keep it lubricated and the slightest variation of the governor balls will be transmitted to the valve, and the speed will be regular.

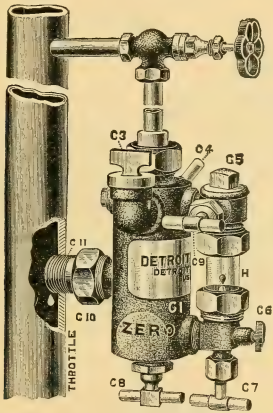


PICKERING HORIZONTAL GOVERNOR.

If the engine has an automatic cut off mechanism actuated by a fly ball governor, it is obvious that all the moving parts of the governor should work with as little friction as possible. Good oil and enough of it should be used. Particular attention should be paid to the dash pot connected with the governor, the object of which is to regulate the variations of the governor and prevent a jerky movement. It often happens, especially with new engines, that the small piston in the dash pot fits too snug, and the consequence is that it sticks; causing the governor to be slow in responding to changes in the speed of the engine.

It is a good plan sometimes to take the dash pot piston out, and putting it in a lathe, reduce its diameter slightly, and also round off the sharp edges. The oil used in the dash pot should not be allowed to become gummy by being used too long without changing it for fresh oil.

Lubrication. The proper lubrication of all the working parts of an engine is a matter of prime importance,



DOUBLE CONNECTION LUBRICATOR.

not only in prolonging the life of the engine, but in reducing friction, and thus increasing efficiency. Various types of lubricators have been devised for introducing oil into the valve chest and cylinder, but probably the most reliable and easily managed apparatus for this purpose is a good oil pump worked by the engine itself, for the reason that it is positive and the flow of oil is not easily affected by changes in

temperature. In the case of large horizontal engines especially, it is good practice to introduce a little graphite along with the cylinder oil once or twice a day.

In many cases trouble is experienced with the bot-

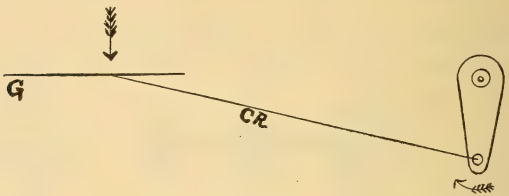


FIGURE 94.

tom guides of horizontal engines, especially if the engine "runs over," as illustrated by Figs. 94 and 95, where it will be seen that in addition to the weight of the crosshead, the thrust or pressure consequent upon the pull, Fig. 94, and push, Fig. 95, also comes upon the bottom guide both with the inward and outward

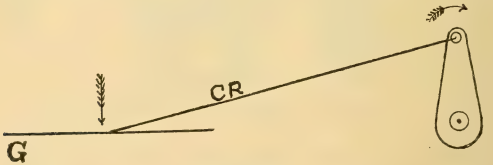


FIGURE 95.

strokes; whereas with an engine "running under," the thrust is just in the opposite direction, and the pressure comes upon the top guide.

The best method of lubricating the lower guide of a horizontal engine is to drill through from the under-

side at a point near the center of the guide, and connect a small size pipe, ⅜ or ½ in., to which an oil or grease cup can be attached. The oil thus forced up from beneath will serve a much better purpose than if dropped on the guide, to be instantly scraped off by the crosshead.

One of the best devices for oiling the crank pin is the center oiler, illustrated in Fig. 96. An oil hole is drilled along the center line of the pin to a point about midway of its length, and another hole from the

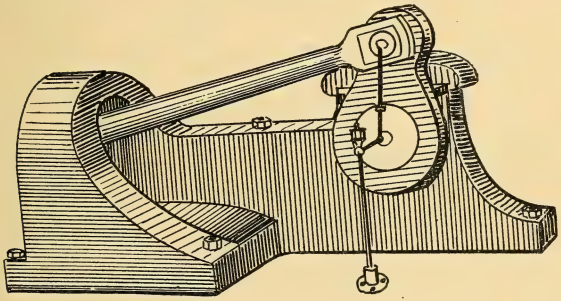


FIGURE 96.

wearing surface of the pin at right angles to the first hole. The two holes meet at the center of the pin and form a route by which the oil is conducted to the point where it is most needed. The hole at the outer end of the pin is enlarged and threaded to receive the oil pipe, one end of which is connected to the pin by means of a short nipple and elbow, while the other end is in line with the center of the main shaft and remains in that position while the crank revolves. The oil is fed into this end of the pipe through an

elbow or hollow ball screwed to the end of the pipe, and the supply may be regulated at will by the engineer, as the cup is at all times under his control.

The pillow block or main bearing of an engine demands and should receive the most careful attention from the engineer, for the reason that there is where the greatest friction occurs, and if neglected for even a short time, trouble will occur.

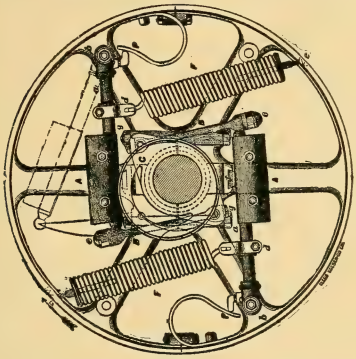
The main bearings of most engines are fitted with apparatus for oiling them by which the oil is dropped upon the top of the journal, when in fact the place that the oil is most needed is at the bottom or underside of the bearing. In horizontal engines, especially, there is a constant pressure on the bottom of the bearing, due to the weight of the flywheel and main shaft, and this pressure prevents the greater part of the oil, if fed in on top, from reaching the lower surface. Therefore the lubrication of pillow blocks may be greatly facilitated by connecting, whenever it is possible to do so, at least one oil pipe in such a way that it will conduct the oil to the bottom of the bearing. In case a pillow block or other bearing shows signs of warming up, good results may often be obtained by using from 25 to 50 per cent. of cylinder oil mixed with the regular engine oil.

Every engineer should establish a regular system of oiling his engine, as for instance, by having regular intervals of time for going around the engine and inspecting all the working parts. A good rule is to make the rounds about every twenty minutes. In this way no part will be neglected, and the danger of having hot bearings or of other accidents happening will be greatly lessened.

Many automatic cut off engines, especially those of

the high speed type, are fitted with isochronal or shaft governors. There are various styles of these governors, but all or nearly all of them control the admission of steam to the cylinder, and consequently the point of cut off by varying the angular advance of the eccentric, which in such engines is free to move across the shaft, being entirely under the control of the governor.

Very close regulation is generally obtained by the



ISOCHRONAL OR SHAFT GOVERNOR, BUCKEYE ENGINE CO.

use of shaft governors, but particular attention should be given to the lubrication of the steam valve, which, with this class of engines, is generally a slide valve of some description, and although it may be ever so nicely balanced, yet if it does not get sufficient oil, the friction due to dry surfaces rubbing together, will put extra work on the governor, and the speed is liable to be irregular.

Keying Up. To keep the working parts of an engine properly keyed up so as to take up the lost motion

without causing the bearings to heat, is one of the most delicate and exacting duties of the engineer. Every engineer worthy of the name should aim to have a smooth and quietly running engine. In fact, this is one of the principal tests of his skill as an engineer.

A few general suggestions may be given here, but much more depends upon the good judgment of the engineer himself.

In connecting up an engine, as for instance, the crank pin and crosshead, the key should first be driven in until it is solid, that is, until the brasses clamp the pin tightly. Then place a small ruler across the face of the gib and key, and with the point of a knife blade, or a steel scriber, make a fine mark along the edge of the ruler. This will be the "solid mark." Now back the key up by light blows with the hammer, which should be of copper, until the brasses are just loose enough on the pin to permit a side movement of the rod. If the rod is very heavy, hold a block of wood against the side of the rod near the pin and give it a blow with a sledge. If there is no movement, back the key a little more, and keep trying until there is a side movement. There should be a space of at least $\frac{1}{32}$ in. between the sides of the brasses and the flange of the pin, so as to allow a slight side play. If it is found, after running a while, that there is too much lost motion, causing the engine to pound, put the ruler across the gib and key again, and with a lead pencil draw a line. Then loosen the set screw and drive the key in a distance equal to the width of the line, and no more. This process should be repeated at intervals until the pound is all gone, or the bearing begins to warm up slightly, indicating that the brasses are up as close as they will run.

The adjustment of pillow blocks also requires a large measure of skill and good judgment, and should be done by degrees; but when once adjusted properly and kept well oiled, the matter of keeping them in good working condition becomes greatly simplified.

If a pillow block, or other bearing filled with babbit metal, should become heated to such a temperature as to cause the metal to run, do not shut down the engine at once and turn on a stream of cold water, because this will only make matters worse, causing the metal to stick to the journal, and the labor and trouble of cleaning it out will be increased. The best method to pursue in such an emergency is to gradually slow the engine down and keep it moving at as slow a speed as it will run, and in the meantime a small stream of cold water may be allowed to flow over the bearing, applying it to all parts as nearly as possible until it is cooled, after which the engine may be stopped and repairs made.

Heating Feed Water. Every steam plant should be provided with one or more heaters for the purpose of utilizing the exhaust steam for heating the feed water, and the exhaust, not only of the engine, but of the feed pumps and all other steam pumps connected with the plant, should be led into it if possible. This applies especially to non-condensing engines, and even if the engine be a condensing engine the exhaust may be passed through a closed heater before going into the condenser.

The percentage of saving in heat effected by heating the feed water with exhaust steam which would otherwise go to waste, may be ascertained by the following rule:

Multiply the difference in the total heat in the

water above 32°, before and after heating, by 100, and divide the product by the total heat required to convert the water into steam from the initial temperature. The quotient will be the per cent. of saving.

The following example will serve to illustrate the process: Suppose the initial temperature of the water to be 50°, and that by means of the heater its temperature is increased to 183° before entering the boiler. The steam pressure being 100 lbs. gauge, or 115 lbs. absolute. By referring to Table 5, it will be seen that

Water at 182.9° temp. contains 151.5 heat units,
" " 50.0° " " 18 " "
The difference = 133.5 heat units.

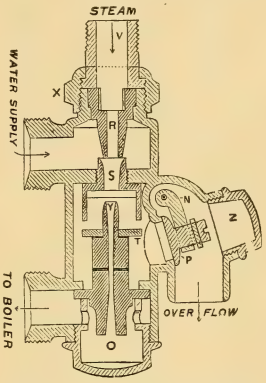
One pound of steam at 115 lbs. absolute pressure contains above 32°, 1,185 heat units, and for each pound of water, at 50°, converted into steam at the above pressure, there would be required 1,185 − 18 = 1167 heat units; but 133.5 heat units having been added to the water while passing through the heater, the problem now becomes $\frac{133.5 \times 100}{1167} = 11.44$ per cent., saving in heat.

Two classes of heaters are available for this purpose, viz., open heaters and closed heaters.

In the open heater the exhaust steam comes in contact with and mingles with the water, and a portion of it is condensed and returns to the boiler. In this respect the open heater has an advantage over the closed type, in which the water is kept separate from the exhaust steam by passing it through tubes that are surrounded by the steam which is confined in the outer shell of the heater. In some types of the closed heater the steam passes through the tubes, which are in turn

surrounded by the water. A heater of either class should be sufficiently large to allow the water to pass through it slowly, in order that it may absorb all the heat possible. About one-third of a square foot of heating surface should be allowed per horse power for a closed heater, and it should have sufficient volume to contain water enough to supply the boilers for a quarter of an hour. If a heater is too small for the engine it is liable to cause back pressure on the exhaust.

There is no saving in heat, but rather a loss in using live steam to heat the feed water, but on the other hand, if the water is bad, it can be purified to a certain extent by passing it through a live steam heater on its way to the boiler.



SECTIONAL VIEW OF PENBERTHY INJECTOR.

Probably the most economical device for feeding boilers is the exhaust injector, which not only feeds the boiler, but utilizes all the available heat in the exhaust steam and returns it to the boiler. The difficulties attending the use of the exhaust injector are that it cannot force water against a pressure above 75 or 80 lbs., and that it will not lift its water supply by suction.

The principle by which an injector is able to force water against a higher pressure than that of the steam by which it is operated, lies in the fact that the mix-

ture of water and steam rushes with such velocity into the vacuum formed by the condensation of the steam, that the momentum thus acquired carries it into the boiler against the higher pressure.

Live steam injectors, while being much less economical than the steam pump with heater, are, nevertheless, a valuable adjunct of a steam plant. They are lifting and non-lifting. A lifting injector in good condition, with no air leaks in the suction pipe, will raise the water by suction about 20 ft. With the non-lifting injector the water supply must flow into the injector, and it may be handled at a temperature as high as 150°, although not so reliable as at lower temperatures.

A good free working check valve and one that will not leak, is one of the most important requisites in the feeding of boilers, and especially is this the case when an injector is used.

Sometimes an injector is prevented from working by dirt being drawn in through the suction pipe. This trouble can be avoided by fitting the pipe with a strainer. If the tubes become clogged with scale, they should be soaked in a dilute solution of muriatic acid, say one part of acid to ten parts of water. All the joints and connections should be air tight, and the valves should be properly packed, otherwise the injector will be a constant source of trouble.

Changing the Speed of an Engine. It sometimes happens that it is desired to permanently change the speed of an engine, and the method of doing this is as follows:

If it is desired to increase the speed but two or three revolutions, it can generally be accomplished by moving the counter balance (which most governors have) farther out on the lever, although there is a limit to

this, because if moved too far, either in, to decrease the speed, or out to increase the speed, the effect will be to destroy the true action of the governor, and its movements will be jerky. The location of the counter balance should be at that point where the governor works the best at the speed at which it was designed to run, and which is generally marked on the governor. And this can only be determined by much patient experimenting on the part of the engineer. If moving the counter balance does not bring about the desired increase of speed, the next move is to increase the diameter of the governor pulley so that the proportions of the pulleys on the engine shaft and the governor will be such that the governor will continue to run at its normal speed, while the speed of the engine has been increased the desired number of revolutions.

To illustrate, assume the engine to be making 75 revolutions per minute, and that the pulley on the engine shaft, upon which the governor belt runs, is 12 in. in diameter, and that the governor pulley is 8 in. in diameter.

Suppose it is desired to increase the speed of the engine to 85 revolutions per minute. First find the speed of the governor with the engine running at 75 revolutions.

The formula is,

$$\frac{\text{Speed of engine} \times \text{diameter of shaft pulley}}{\text{Diameter of governor pulley}} = \text{speed of governor.}$$

Thus, $\frac{75 \times 12}{8} = 112.5$, revolutions for governor.

Next find what the diameter of the governor pulley must be to allow the governor to still run at 112.5 revolutions while the engine runs at 85 revolutions.

The formula is,

$$\frac{\text{Speed of engine} \times \text{diameter of shaft pulley}}{\text{Speed of governor}} = \text{diameter}$$

of governor pulley. Thus, $\frac{85 \times 12}{112.5} = 9.06$ in., diameter of new pulley required for governor.

Should it be desired to decrease the speed of the engine, the same rules and formula will apply for ascertaining the diameter of the governor pulley, which in this case would have to be reduced in size.

Questions

1. Into what two general classes may engines be divided?
2. In what respect do they differ?
3. What advantage has a compound engine over a simple engine?
4. What advantage economically has a condensing engine over a non-condensing engine?
5. How many kinds of condensers are there?
6. Describe a jet condenser.
7. Describe a surface condenser.
8. Is an air pump absolutely necessary with all jet condensers?
9. What is meant by an independent air pump and condenser?
10. What three factors determine the quantity of condensing water required by an engine?
11. What is the rule for ascertaining the quantity of condensing water required by an engine?
12. How may the quantity of condensing water required per horse power per hour be ascertained?
13. What precautions should be observed with a throttling governor?

14. What general rules should be followed in the operation of an automatic cut off governor?

15. What is the most reliable device for introducing oil into the valve chest and cylinder?

16. How may the bottom guide of a horizontal engine be best lubricated?

17. What reliable device may be used in the lubrication of the crank pin?

18. What precautions should be observed in the lubrication of the main bearings or pillow blocks?

19. What should be done with a pillow block that shows signs of warming up?

20. How does an isochronal, or shaft governor, regulate the speed of an engine?

21. How is the shaft governor affected if the steam valve is not properly lubricated?

22. Describe the proper method of keying up an engine.

23. What should be done in case a main bearing becomes heated sufficiently to melt the babbitt?

24. How may the exhaust be utilized to an advantage?

25. What is the rule for ascertaining the percentage of saving in heat when an exhaust heater is used?

26. What two classes of heaters are available?

27. What is an open heater?

28. Describe a closed heater.

29. Is there a saving in heat effected by using a live steam heater?

30. What advantage then is derived from its use?

31. Upon what principle does an injector work?

32. Into what two types are injectors divided?

33. What particular valve in the feed pipe of a boiler should always be kept in good condition?

34. How may an injector that has become clogged with dirt or scale be cleaned?

35. What precautions should be observed in fitting up an injector?

36. How may the speed of an engine be slightly increased?

37. If it is desired to increase the speed considerably, how may it be done?

38. If it is desired to decrease the speed, what changes are necessary?

Engineering

PART II

INTRODUCTION TO PART II

In Chapters I, II and III of Part I the construction, setting and operation of steam boilers is treated upon at some length, but as there is a constant demand in the manufacturing world for higher steam pressures, the author considers that it would no doubt be of great benefit to his readers if these topics were dealt with more in detail. This is done in Chapters I and II, and the subject of mechanical stokers and furnaces is taken up in Chapter III.

Since the inauguration of the twentieth century there has been introduced to the engineering profession a comparatively new prime mover, in the shape of the steam turbine, and judging from present indications it has come to stay. Therefore it behooves engineers to make themselves acquainted with it, and the sooner they do so the more will they be benefited by the advent of this stranger.

In the remaining portion of Part II the author has endeavored to lay before his readers a plain, practical description of each one of the four leading types of steam turbines that are being manufactured and used in this country at the present time.

C. F. S.

April, 1905.

Engineering

PART II

CHAPTER I

THE BOILER

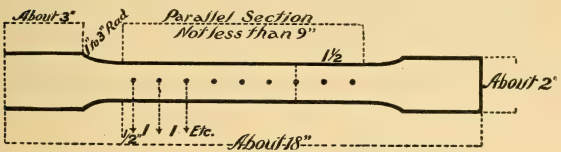
Importance of correct knowledge of the construction and strength of steam boilers—Tensile strength of steel boiler plates—Dr. Thurston's specifications—Specifications of U. S. board of inspectors of steam vessels—Punched and drilled plates—Rivets and rivet iron and steel—Efficiency of the joints—Proportions of double riveted butt joints—Lloyd's rules for thickness of plate and diameter of rivets—Correct design of triple riveted butt joints—Calculations for efficiency of different forms of joints—Discussion of various ways in which failure may occur in different styles of joints—Necessity for higher efficiencies in riveted joints—Quadruple and quintuple butt joints—Staying flat surfaces—Different methods of staying a boiler—Correctly designed stays—Stay bolts for fire box boilers—The Belpaire boiler—Vanderbilt Locomotive with Morison fire box—Gusset stays—Through stay rods—Calculating strength of stayed surfaces—Area of segments—Proper spacing of stays—Strength of unstayed surfaces—Dished heads—Welded seams.

As it is of the highest importance, not only to the engineer in charge of the plant, but also to his assistants, and in fact to all persons whose business compels them to be in the vicinity of the boiler-room, that there should be absolutely no doubt as to the safe construction of the boilers and their ability to withstand the pressures under which they are operated, the

author has compiled the following additional data regarding the construction and strength of boilers. The deductions and reports of tests and experiments made by such eminent authorities as Dr. Thurston, Prof. Wm. Kent, Dr. Peabody, D. K. Clark, Hutton and many other experts have been consulted, and the author has also added the results of his own observations, collected during an experience of thirty-five years as a practical engineer.

When steel was first introduced as a material for boiler plate, it was customary to demand a high tensile strength, 70,000 to 74,000 lbs. per sq. in., but experience and practice demonstrated in course of time that it was much safer to use a material of lower tensile strength. It was found that with steel boiler plate of high tenacity there was great liability of its cracking, and also of certain changes occurring in its physical properties, brought about by the variations in temperature to which it was exposed. Consequently present-day specifications for steel boiler plate call for tensile strengths running from 55,000 to 66,000 lbs., usually 60,000 lbs. per sq. in. Dr. Thurston gives what he calls "good specifications" for boiler steel as follows: "Sheets to be of uniform thickness, smooth finish, and sheared closely to size ordered. Tensile strength to be 60,000 lbs. per sq. in. for fire box sheets and 55,000 lbs. per sq. in. for shell sheets. Working test: a piece from each sheet to be heated to a dark cherry red, plunged into water at 60° and bent double, cold, under the hammer. Such piece to show no flaw after bending. The U. S. Board of Supervising Inspectors of Steam Vessels prescribes, in Section 3 of General Rules and Regulations, the following method for ascertaining the tensile strength of steel plate for

boilers: "There shall be taken from each sheet to be used in shell or other parts of boiler which are subject to tensile strain, a test piece prepared in form according to the following diagram:



TEST PIECE.

The straight part in center shall be 9 in. in length and 1 in. in width, marked with light prick punch marks at distances 1 in. apart, as shown, spaced so as to give 8 in. in length. The sample must show, when tested, an elongation of at least 25 per cent in a length of 2 in. for thickness up to ¼ in. inclusive; in a length of 4 in., for over ¼ in. to $\frac{7}{16}$ in. inclusive; in a length of 6 in., for all plates over $\frac{7}{16}$ in. and under 1¾ in. in thickness. The samples shall also be capable of being bent to a curve of which the inner radius is not greater than 1½ times the thickness of the plates, after having been heated uniformly to a low cherry red and quenched in water of 82° F."

Punched and Drilled Plates. Much has been written on this subject, and it is still open for discussion. If the material is a good, soft steel, punched sheets are apparently as strong and in some instances stronger than drilled, especially is this the case with regard to the shearing resistance of the rivets, which is greater with punched than with drilled holes.

Concerning rivets and rivet iron and steel Dr.

Thurston has this to say in his "Manual of Steam Boilers": "Rivet iron should have a tenacity in the bar approaching 60,000 lbs. per sq. in., and should be as ductile as the very best boiler plate when cold. A good 5/8-in. iron rivet can be doubled up and hammered together cold without exhibiting a trace of fracture." The shearing resistance of iron rivets is about 85 per cent and that of steel rivets about 77 per cent of the tenacity of the original bar, as shown by experiments made by Greig and Eyth. The researches made by Wöhler demonstrated that the shearing strength of iron was about four-fifths of the tensile strength.

The tables that follow have been compiled from the highest authorities and show the results of a long and exhaustive series of tests and experiments made in order to ascertain the proportions of riveted joints that will give the highest efficiencies.

The following Table 11 gives the diameters of rivets for various thicknesses of plates and is calculated according to a rule given by Unwin.

TABLE 11

TABLE OF DIAMETERS OF RIVETS*

Thickness of Plate	Diameter of Rivet	Thickness of Plate	Diameter of Rivet
1/4 inch	1/2 inch	9/16 inch	7/8 inch
5/16 "	9/16 "	5/8 "	15/16 "
3/8 "	11/16 "	3/4 "	1 1/16 "
7/16 "	3/4 "	7/8 "	1 1/8 "
1/2 "	13/16 "	1 "	1 1/4 "

The efficiency of the joint is the percentage of the strength of the solid plate that is retained in the joint,

*Machine design—W. C. Unwin.

and it depends upon the kind of joint and method of construction.

If the thickness of the plate is more than ½ in., the joint should always be of the double butt type.

The diameters of rivets, rivet holes, pitch and efficiency of joint, as given in the following Table 12, which was published in the "Locomotive" several years ago, were adopted at the time by some of the best establishments in the United States.*

TABLE 12

PROPORTIONS AND EFFICIENCIES OF RIVETED JOINTS

	Inch	Inch	Inch	Inch	Inch
Thickness of plate	1/4	5/16	3/8	7/16	1/2
Diameter of rivet	5/8	11/16	3/4	13/16	7/8
Diameter of rivet-hole	11/16	3/4	13/16	7/8	15/16
Pitch for single riveting	2	2 1/16	2 1/8	2 3/16	2 1/4
Pitch for double riveting	3	3 1/8	3 1/4	3 3/8	3 1/2
Efficiency—single-riveted joint	.66	.64	.62	.60	.58
Efficiency—double-riveted joint	.77	.76	.75	.74	.73

Concerning the proportions of double-riveted butt joints, Prof. Kent says: "Practically it may be said that we get a double-riveted butt joint of maximum strength by making the diameter of the rivet about 1.8 times the thickness of the plate, and making the pitch 4.1 times the diameter of the hole."

Table 13 as given below is condensed from the report of a test of double-riveted lap and butt joints.† In

*Thurston's "Manual of Steam Boilers."

†Proc. Inst. M. E., Oct., 1888.

this test the tensile strength of the plates was 56,000 to 58,000 lbs. per sq. in., and the shearing resistance of the rivets (steel) was about 50,000 lbs. per sq. in.

TABLE 13

DIAMETER AND PITCH OF RIVETS—DOUBLE-RIVETED JOINT

Kind of Joint	Thickness of Plate	Diameter of Rivet	Ratio of Pitch to Diameter
Lap	$\frac{3}{8}$ inch	0.8 inches	3.6 inches
Butt	$\frac{3}{8}$ "	0.7 "	3.9 "
Butt	$\frac{3}{4}$ "	1.1 "	4.0 "
Butt	1 "	1.3 "	3.9 "

Lloyd's rules, condensed, are as follows:

LLOYD'S RULES—THICKNESS OF PLATE AND DIAMETER OF RIVETS

Thickness of Plate	Diameter of Rivets	Thickness of Plate	Diameter of Rivets
$\frac{3}{8}$ inch	$\frac{5}{8}$ inch	$\frac{3}{4}$ "	$\frac{7}{8}$ inch
$\frac{7}{16}$ "	$\frac{5}{8}$ "	$\frac{13}{16}$ "	$\frac{7}{8}$ "
$\frac{1}{2}$ "	$\frac{3}{4}$ "	$\frac{7}{8}$ "	1 "
$\frac{9}{16}$ "	$\frac{3}{4}$ "	$\frac{15}{16}$ "	1 "
$\frac{5}{8}$ "	$\frac{3}{4}$ "	1 "	1 "
$\frac{11}{16}$ "	$\frac{7}{8}$ "		

The following Table 14 is condensed from one calculated by Prof. Kent,* in which he assumes the shearing strength of the rivets to be four-fifths of the tensile strength of the plate per square inch, and the excess strength of the perforated plate to be 10 per cent.

* Kent's "Mechanical Engineer's Pocket-Book," page 362.

TABLE 14

Thickness of Plate	Diameter of Hole	Pitch		Efficiency	
		Single Riveting	Double Riveting	Single Riveting	Double Riveting
Inches	Inches	Inches	Inches	Per Cent	Per Cent
3/8	7/8	2.04	3.20	57.1	72.7
7/16	1	2.30	3.61	56.6	72.3
1/2	1	2.14	3.28	53.3	70.0
1/2	1 1/8	2.57	4.01	56.2	72.0
9/16	1	2.01	3.03	50.4	67.0
9/16	1 1/8	2.41	3.69	53.3	69.5
9/16	1 1/4	2.83	4.42	55.9	71.5
5/8	1	1.91	2.82	47.7	64.6
5/8	1 1/8	2.28	3.43	50.7	67.3
5/8	1 1/4	2.67	4.10	53.3	69.5

Another table of joint efficiencies as given by Dr. Thurston* is as follows, slightly condensed from the original calculation:

TABLE 15

Single riveting								
Plate thickness.	5/16''	3/8''	7/16''	1/2''	5/8''	3/4''	7/8''	1''
Efficiency.....	.55	.55	.53	.52	.48	.47	.45	.43

Double riveting						
Plate thickness.	3/8''	7/16''	1/2''	3/4''	7/8''	1''
Efficiency.....	.73	.72	.71	.66	.64	.63

The author has been at considerable pains to compile Tables 16, 17 and 18, giving proportions and efficiencies of single lap, double lap and butt, and triple-riveted butt joints. The highest authorities have been consulted in the computation of these tables and great care exercised in the calculations.

*Thurston's "Manual of Steam Boilers," page 119.

TABLE 16

PROPORTIONS OF SINGLE-RIVETED LAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Efficiency Per Cent
5/16	9/16	1.13	50.5
"	5/8	1.33	53.3
"	11/16	1.55	55.7
3/8	3/4	1.60	53.3
"	7/8	2.04	57.1
7/16	7/8	1.87	53.2
"	1	2.30	56.6
1/2	1	2.14	53.3
"	1 1/8	2.57	56.2
9/16	1	2.01	50.4
"	1 1/8	2.41	53.3
"	1 1/4	2.83	55.9
5/8	1 1/8	2.28	50.7
"	1 1/4	2.67	53.3

It will be noticed that in single-riveted lap joints the highest efficiencies are attained when the diameter of the rivet hole is about 2⅓ times the thickness of the plate, and the pitch of the rivet 2⅜ times the diameter of the hole.

With the double-riveted joint it appears, according to Table 17, that in order to obtain the highest efficiency the joint should be designed so that the diameter of the rivet hole will be from 1⅘ to 2 times the thickness of plate, and the pitch should be from 3⅓ to 3½ times the diameter of the hole. Concerning the thickness of plates Dr. Thurston has this to say:* "Very thin plates cannot be well caulked, and thick plates cannot be safely riveted. The limits are about ¼ of an inch for the lower limit, and ¾ of an inch for the higher limit." The riveting machine, however, overcomes the difficulty with very thick plates.

* Thurston's "Manual of Steam Boilers," page 120.

TABLE 17

PROPORTIONS OF DOUBLE-RIVETED LAP AND BUTT JOINTS

Thickness of Plate	Diameter of Rivet	Pitch of Rivet	Efficiency
5/16 inch	9/16 inch	1.71 inches	67.1 per cent
5/16 "	5/8 "	2.05 "	69.5 "
3/8 "	3/4 "	2.46 "	69.5 "
3/8 "	7/8 "	3.20 "	72.7 "
7/16 "	3/4 "	2.21 "	66.2 "
7/16 "	7/8 "	2.86 "	69.4 "
7/16 "	1 "	3.61 "	72.3 "
1/2 "	1 "	3.28 "	70.0 "
1/2 "	1 1/8 "	4.01 "	72.0 "
9/16 "	1 "	3.03 "	67.0 "
9/16 "	1 1/8 "	3.69 "	69.5 "
9/16 "	1 1/4 "	4.42 "	71.5 "
5/8 "	1 1/8 "	3.43 "	67.3 "
5/8 "	1 1/4 "	4.10 "	69.5 "
3/4 "	1 "	2.50 "	72.0 "
7/8 "	1 1/8 "	3.94 "	74.2 "
1 "	1 1/4 "	4.10 "	76.1 "

The triple-riveted butt joint with two welts, one inside and one outside, has two rows of rivets in double shear and one outer row in single shear on each side of the butt, the pitch of rivets in the outer rows being twice the pitch of the inner rows. One of the welts is wide enough for the three rows of rivets each side of the butt, while the other welt takes in only the two close pitch rows.

When properly designed, this form of joint has a high efficiency, and is to be relied upon. Table 18 gives proportions and efficiencies, and it will be noted that the highest degree of efficiency is shown when the diameter of rivet hole is from 1¼ to 1½ times the thickness of plate, and the pitch of the rivets is from 3½ to 4 times the diameter of the hole. This, of

course, refers to the pitch of the close rows of rivets, and not the two outer rows.

TABLE 18

PROPORTIONS OF TRIPLE-RIVETED BUTT JOINTS WITH INSIDE AND OUTSIDE WELT

Thickness of Plate Inches	Diameter of Rivet Inches	Pitch of Rivet Inches	Pitch of Outer Rows Inches	Efficiency Per Cent
3/8	13/16	3.25	6.5	84
7/16	13/16	3.25	6.5	85
1/2	13/16	3.25	6.5	83
9/16	7/8	3.50	7.0	84
5/8	1	3.50	7.0	86
3/4	1 1/16	3.50	7.0	85
7/8	1 1/8	3.75	7.5	86
1	1 1/4	3.87	7.7	84

Some simple rules are given in Chapter I, Part I, for finding the percentage of efficiency, or in other words the ratio of the strength of the riveted joint to the strength of the solid plate. In those calculations the tensile strength of the rivets was assumed to be 38,000 to 40,000 lbs. per sq. in. The highest efficiency is attained in a riveted joint when the tensile strength of the rods from which the rivets are cut approaches that of the plates, and when the proportions of the joint are such that the tensile strength of the plates, the shearing strength of the rivets, and the crushing resistance of the rivets and plate, for a given section or unit strip, are as nearly equal as it is possible to secure them.

A few examples of calculations for efficiency will be given, taking the three forms of riveted joints in most common use. The following notation will be used throughout:

T.S. = Tensile strength of plate per square inch.
T = Thickness of plate.
C = Crushing resistance of plate and rivets.
A = Sectional area of rivets.
S = Shearing strength of rivets.
D = Diameter of hole (also diameter of rivets when driven).
P = Pitch of rivets.

In the calculations that follow T.S. will be assumed to be 60,000 lbs., S will be taken at 45,000 lbs., and the value of C may be assumed to be 90,000 to 95,000.

Fig. 97 shows a double-riveted lap joint. The style of riveting in this joint is what is known as chain riveting.

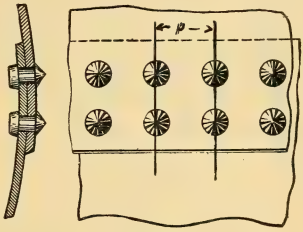


FIGURE 97.

In case the rivets are staggered, the same rules for calculating the efficiency will hold as with chain riveting, for the reason that with either style of riveting the unit strip of plate has a width equal to the pitch or distance *p*, Fig. 97.

The dimensions of the joint under consideration are as follows: P = 3¼ in., T = $\frac{7}{16}$ in., D = 1 in. (which is also diameter of driven rivet).

The strength of the unit strip of solid plate is P × T × T.S. = 85,312.

The strength of net section of plate after drilling is P − D × T × T.S. = 59,062.

The shearing resistance of two rivets is 2A × S = 70,686.

The crushing resistance of rivets and plate is $D \times 2 \times T \times C = 78{,}750$.

It thus appears that the weakest part of the joint is the net strip or section of plate, the strength of which is 59,062 and the efficiency = $59{,}062 \times 100 \div 85{,}312 = 69.2$ per cent.

A double-riveted butt joint is illustrated by Fig. 98, and the dimensions are as follows:

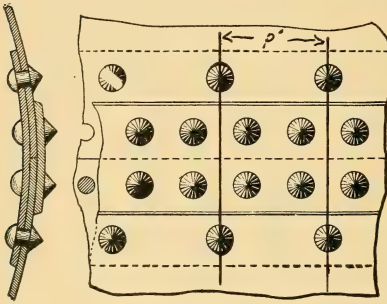


FIGURE 98.

P, inner row of rivets = $2\frac{3}{4}$ in.

P', outer row of rivets = $5\frac{1}{2}$ in.

T of plate and butt straps = $\frac{7}{16}$ in.

D of hole and driven rivet = 1 in.

Failure may occur in this joint in five distinct ways, which will be taken up in their order.

1. Tearing of the plate at the outer row of rivets. The net strength at this point is $P - D \times T \times T.S.$, which, expressed in plain figures, results as follows: $5.5 - 1 \times .4375 \times 60{,}000 = 118{,}125$.

2. Shearing two rivets in double shear and one in single shear. Should this occur, the two rivets in the inner row would be sheared on both sides of the plate, thus being in double shear. Opposed to this strain there are four sections of rivets, two for each rivet. Then at the outer row of rivets in the unit strip there is the area of one rivet in single shear to be added.

The total resistance, therefore, is $5A \times S$ as follows: $.7854 \times 5 \times 45{,}000 = 176{,}715$.

3. The plate may tear at the inner row of rivets and shear one rivet in the outer row. The resistance in this case would be $P' - 2D \times T \times T.S. + A \times S$ as follows: $5.5 - 2 \times .4375 \times 60{,}000 + .7854 \times 45{,}000 = 127{,}218$.

4. Failure may occur by crushing in front of three rivets. Opposed to this is $3D \times T \times C$, or $1 \times 3 \times .4375 \times 95{,}000 = 124{,}687$.

5. Failure may occur by crushing in front of two rivets and shearing one. The resistance is represented by $2D \times T \times C + 1A \times S$; expressed in figures, $1 \times 2 \times .4375 \times 95{,}000 + .7854 \times 45{,}000 = 118{,}468$.

The strength of a solid strip of plate 5½ in. wide before drilling is $P' \times T \times T.S.$, or $5.5 \times .4375 \times 60{,}000 = 144{,}375$, and the efficiency of the joint is $118{,}125 \times 100 \div 144{,}375 = 81.1$ per cent.

A triple-riveted butt joint is shown in Fig. 99, the dimensions of which are as follows:

$T = \frac{7}{16}$ in.
$D = \frac{15}{16}$ in.
$A = .69$ in.
$P = 3\frac{3}{8}$ in.
$P' = 6\frac{3}{4}$ in.

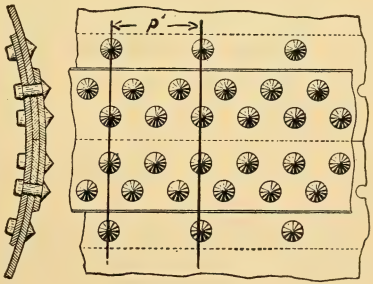


FIGURE 99.

Failure may occur in this joint in either one of five ways.

1. By tearing the plate at the outer row of rivets where the pitch is 6¾ in. The net strength of the unit

strip at this point is $P' - D \times T \times T.S.$, found as follows: $6.75 - .9375 \times .4375 \times 60{,}000 = 152{,}578$.

2. By shearing four rivets in double shear and one in single shear. In this instance, of the four rivets in double shear, each one presents two sections, and the one in single shear presents one, thus making a total of nine sections of rivets to be sheared, and the strength is $9A \times S$, or $.69 \times 9 \times 45{,}000 = 279{,}450$.

3. Rupture of the plate at the middle row of rivets and shearing one rivet. Opposed to this strain the strength is $P' - 2D \times T \times T.S. + 1A \times S$, equivalent to $6.75 - (.9375 \times 2) \times .4375 \times 60{,}000 + .69 \times 90{,}000 = 190{,}068$.

4. Crushing in front of four rivets and shearing one rivet. The resistance in this instance is $4D \times T \times C + 1A \times S$, or $.9375 \times 4 \times .4375 \times 90{,}000 + .69 \times 45{,}000 = 178{,}706$.

5. Failure may be caused by crushing in front of five rivets, four of which pass through both the inside and outside butt straps, while the fifth rivet passes through the inside strap only, and the resistance is $5D \times T \times C$, equivalent to $.9375 \times 5 \times 90{,}000 = 184{,}570$.

The strength of the unit strip of plate before drilling is $P' \times T \times T.S.$, or $6.75 \times .4375 \times 60{,}000 = 177{,}187$, and the efficiency is $152{,}578 \times 100 \div 177{,}187 = 86$ per cent.

With the constantly increasing demand for higher steam pressures, the necessity for higher efficiencies in the riveted joints of boilers becomes more apparent, and of late years quadruple and even quintuple-riveted butt joints have in many instances come into use. The quadruple butt joint when properly designed shows a

high efficiency, in some cases as high as 94.6 per cent. Fig. 100 illustrates a joint of this kind, and the dimensions are as follows:

T = ½ in.
D = $\frac{15}{16}$ in.
A = .69 in.
P, inner rows = 3¾ in.
P′, 1st outer row = 7½ in.
P″, 2d outer row = 15 in.

The two inner rows of rivets extend through the

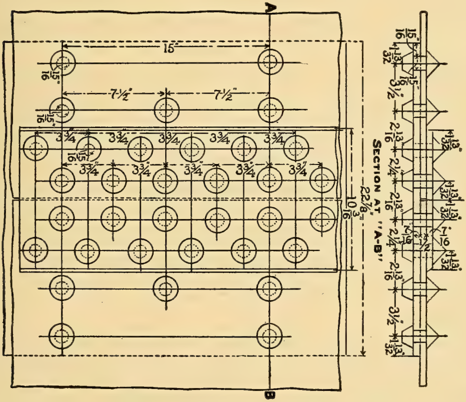


FIGURE 100.

main plate and both the inside and outside cover plates or butt straps.

The two outer rows reach through the main plate and inside cover plate only, the first outer row having twice the pitch of the inner rows, and the second outer row has twice the pitch of the first.

Taking a strip or section of plate 15 in. wide (pitch of outer row), there are four ways in which this joint may fail.

1. By tearing of the plate at the outer row of rivets. The resistance is $P'' - D \times T \times T.S.$, or $15 - .9375 \times .5 \times 60{,}000 = 421{,}875$.

2. By shearing eight rivets in double shear and three in single shear. The strength in resistance is $19A \times S$, or $.69 \times 19 \times 45{,}000 = 589{,}950$.

3. By tearing at inner rows of rivets and shearing three rivets. The resistance is $P'' - 4D \times T \times T.S. + 3A \times S$, or $15 - (.9375 \times 4) \times .5 \times 60{,}000 + .69 \times 3 \times 45{,}000 = 430{,}650$.

4. By tearing at the first outer row of rivets, where the pitch is 7½ in., and shearing one rivet. The resistance is $P'' - 2D \times T \times T.S. + A \times S$, or $15 - (.9375 \times 2) \times .5 \times 60{,}000 + .69 \times 45{,}000 = 424{,}800$.

It appears that the weakest part of the joint is at the outer row of rivets, where the net strength is 421,875. The strength of the solid strip of plate 15 in. wide before drilling is $P'' \times T \times T.S.$, or $15 \times .5 \times 60{,}000 = 450{,}000$, and the efficiency is $421{,}875 \times 100 \div 450{,}000 = 93.7$ per cent.

Staying Flat Surfaces. The proper staying or bracing of all flat surfaces in steam boilers is a highly important problem, and while there are various methods of bracing resorted to, still, as Dr. Peabody says, "the staying of a flat surface consists essentially in holding it against pressure at a series of isolated points which are arranged in regular or symmetrical pattern." The cylindrical shell of a boiler does not need bracing for the very simple reason that the internal pressure tends to keep it cylindrical. On the contrary the internal pressure has a constant tendency to bulge out the flat

surface. Rule 2, Section 6, of the rules of the U. S. Supervising Inspectors provides as follows: "No braces or stays hereafter to be employed in the construction of boilers shall be allowed a greater strain than 6,000 lbs. per sq. in. of section."

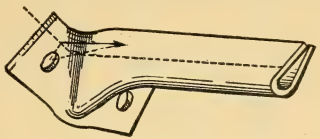


FIGURE 101.

The method to be employed in staying a boiler depends upon the type of boiler and the pressure to be carried. Formerly when comparatively low pressures were used (60 to 75 lbs. per sq. in.) the diagonal crow foot brace was considered amply sufficient for staying the flat heads of boilers of the cylindrical tubular type, both above and below the tubes, but in the present age, when much higher pressures are demanded, through stay rods are largely employed. These are soft steel or iron rods 1¼ to 2 in. in diameter, extending through from head to head, with a pull at right angles to the plate, thus having a great advantage over the diagonal stay in that the pull on the diagonal tay per square inch of section is more than 5 per cent in excess of what a through stay would have to resist under the same conditions of pressure, etc.

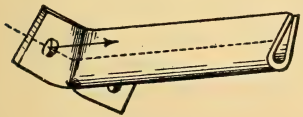


FIGURE 102.

The method of calculation for diagonal bracing is given in Chapter I and will not be discussed here.

The weakest portion of the crow foot brace when in position is at the foot end, where it is connected to the head by two rivets. With a correctly designed brace

the pull on these rivets is direct and the tensile strength of the material needs to be considered only, but if the form of the brace is such as to bring the rivet holes above or below the center line of the brace, or if the rivets are pitched too far from the body of the brace, there will be a certain leverage exerted upon the rivets in addition to the direct pull. Fig. 101 shows a brace of incorrect design and Figs. 102 and 103 show braces designed along correct lines.

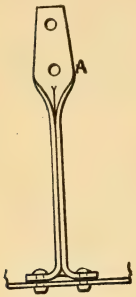


FIGURE 103.

Other methods of staying, besides the crow foot brace and through stays, consist of gusset stays, and for locomotives and other fire box boilers screwed stay bolts are employed to tie the fire box to the external shell. The holes for these stay bolts are punched or drilled before the fire box is put in place. After it is in and riveted along the lower edge to the foundation ring, or mud ring as it is sometimes called, a continuous thread is tapped in the holes in both the outside plate and the fire sheet by running a long tap through both plates. The steel stay bolt is then screwed through the plates and allowed to project enough at each end to permit of its being riveted cold. Stay bolts are liable to be broken by the unequal expansion of the fire box and outer shell, and a small hole should be drilled in the center of the bolt, from the outer end nearly through to the inner end. Then in case a bolt breaks, steam or water will blow out through the small hole, and the break will be discovered at once. The problem of properly staying the flat crown sheet of a horizontal fire box boiler, especially a locomotive

boiler, is a very difficult one and has taxed the inventive genius of some of the most eminent engineers.

Before the invention of the Belpaire boiler, with its outside or shell plate flat above the fire box, the only method of staying the crown sheet was by the use of cumbersome crown bars or double girders extending across the top of the crown sheet and supported at the ends by special castings that rest on the edges of the side sheets and on the flange of the crown sheet. At intervals of 4 or 5 in. crown bolts are placed, having the head inside the fire box and the nut bearing on a plate on top of the girder. There is also a thimble for each bolt to pass through, between the top of the crown sheet and the girder. These thimbles maintain the proper distance between the crown sheet and girder and allow the water to circulate freely.

The Belpaire fire box dispenses with girders and permits the use of through stays from the top of the flat outside plate through the crown sheet and secured at each end by nuts and copper washers.

For simplicity of construction and great strength the cylindrical form of fire box known as the Morison corrugated furnace has proved to be very successful. This form of fire box was in 1899 applied to a locomotive by Mr. Cornelius Vanderbilt, at the time assistant superintendent of motive power of the New York Central and Hudson River R. R. This furnace was rolled of ¾-in. steel, is 59 in. internal diameter and 11 ft. 2¼ in. in length. It was tested under an external pressure of 500 lbs. per sq. in. before being placed in the boiler. It is carried at the front end by a row of radial sling stays from the outside plate, and supported at the rear by the back head. Figs. 104 and 105 show respectively a sectional view and an end elevation of

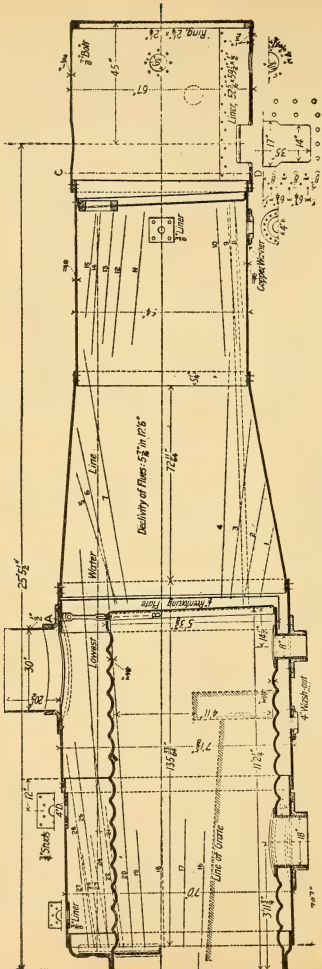


FIGURE 104.

this boiler. It will be seen at once that the question of stays for a fire box of this type becomes very simple. The boiler has proved to be so satisfactory that the company has since had five more of the same type constructed.

Gusset stays are used mainly in boilers of the Lancashire model and are triangular-shaped plates sheared to the proper form and having two angle irons riveted to the edges that come against the shell and the head. The angle irons are then riveted to the shell and the flat head. This form of brace is simple and solid, but its chief defect is, that it is very rigid

and does not allow for the unequal expansion of the internal furnace flues and the shell. Fig. 106 illustrates a gusset stay and the method of applying it.

Coming now to through stay rods, it is safe to say that whenever and wherever it is possible to apply them they should be used. In all cases they should

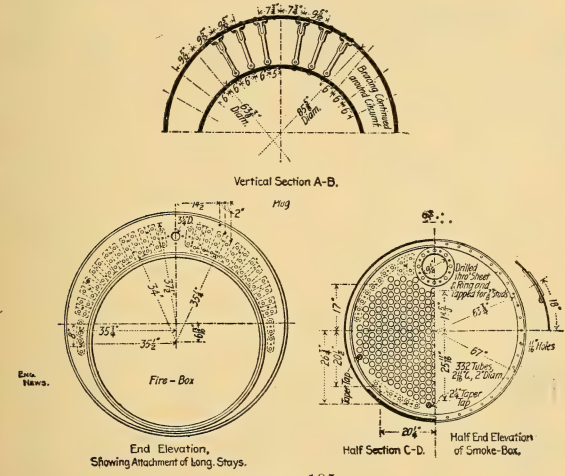


FIGURE 105.

be placed far enough apart to allow a man to pass between them for the purposes of inspection and washing out of the boiler. Through stay rods are usually spaced 14 in. apart horizontally and about the same distance vertically. The ends, as far back as the threads run, are swaged larger than the body, so that the diameter at the bottom of the thread is greater than the diameter of the body. There are several

methods of applying through stays. One of the most common, especially for land boilers, is to allow the ends of the rod to project through the plates to be stayed, and holding them in place by a nut and copper washer, both inside and outside the plate. Another and still better plan is to rivet 6-in. channel bars across the head, inside above the tubes, the number of bars depending upon the height of the segment to be stayed.

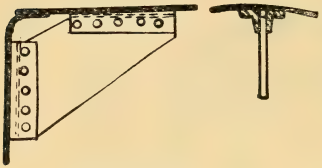


FIGURE 106.

The channel bars are drilled to correspond with the holes that are drilled in the plate to receive the stay rods, which latter are then secured by inside and outside nuts and copper washers.

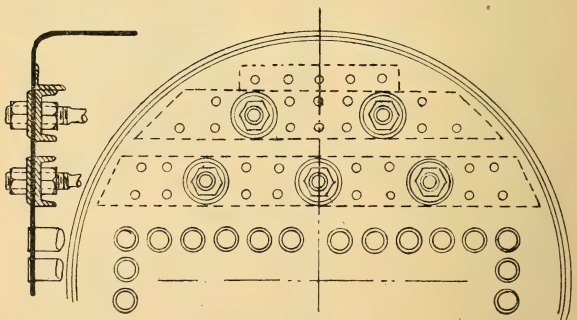


FIGURE 107.

These channel bars act as girders and serve to greatly strengthen the head or flat plate. Fig. 107 will serve to illustrate this method.

Sometimes a combination of channel bar and diagonal crow foot braces is used, as shown by Fig. 108.

A good form of diagonal crow foot stay is obtained by using double crow feet, made of pieces of boiler plate bent as shown by Fig. 109 and riveted to the plate by four rivets. A hole is drilled through the body of the crow foot, and a bolt passing through this secures the forked end of the stay.

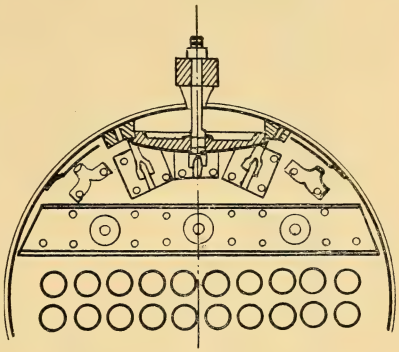


FIGURE 108.

Another method of securing through stays to the heads is shown by Fig. 110 and is applied where too many stay rods would be required to connect all the points to be stayed. A tee iron is first riveted to the flat plate to be stayed, and two V-shaped forgings are bolted to it as shown. The through stay is then bolted to the forgings, and thus two points in the flat head are supported by one stay. It will readily be seen that this method will reduce the number of through stay rods required.

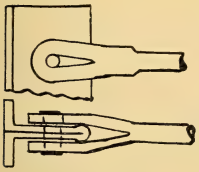


FIGURE 109.

Calculating the Strength of Stayed Surfaces. In calculations for ascertaining the strength of stayed sur-

faces, or for finding the number of stays required for any given flat surface in a boiler, the working pressure being known, it must be remembered that each stay is subjected to the pressure on an area bounded by lines drawn midway between it and its neighbors. Therefore the area in square inches, of the surface to

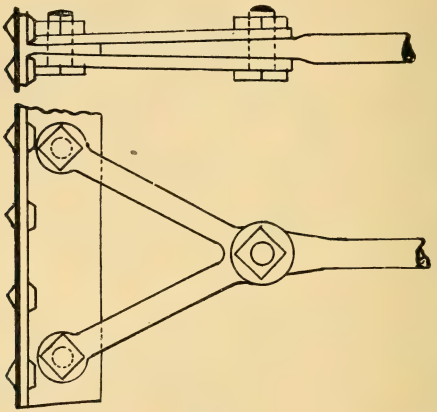


FIGURE 110.

be supported by each stay, equals the square of the pitch or distance in inches between centers of the points of connection of the stays to the flat plate. Thus, suppose the stays in a certain boiler are spaced 8 in. apart, the area sustained by each stay = $8 \times 8 =$ 64 sq. in., or assume the stay bolts in a locomotive fire box to be pitched $4\frac{1}{2}$ in. each way, the area supported by each stay bolt = $4\frac{1}{2} \times 4\frac{1}{2} = 20\frac{1}{4}$ sq. in. Again taking through stay rods, suppose, for example,

the through stays shown in Fig. 107 to be spaced 15 in. horizontally and 14 in. vertically, the area supported by each stay = 15 × 14 = 210 sq. in.

The minimum factor of safety for stays, stay bolts and braces is 8, and this factor should enter into all computations of the strength of stayed surfaces.

The pitch for stays depends upon the thickness of the plate to be supported, and the maximum pressure to be carried.

In computing the total area of the stayed surface it is safe to assume that the flange of the plate, where it is riveted to the shell, sufficiently strengthens the plate for a distance of 2 in. from the shell, also that the tubes act as stays for a space of 2 in. above the top row. Therefore the area of that portion of the flat head or plate bounded by an imaginary line drawn at a distance of 2 in. from the shell and the same distance from the last row of tubes is the area to be stayed. This surface may be in the form of a segment of a circle, as with a horizontal cylindrical boiler, or it may be rectangular in shape, as in the case of a locomotive or other fire box boiler. Other forms of stayed surfaces are often encountered, but in general the rules applicable to segments or rectangular figures will suffice for ascertaining the areas.

The method of finding the area of the segmental portion of the head above the tubes is given in Chapter I, pages 22 and 23, and will not be enlarged upon here, except to add Table 19, which covers a much greater number of segments than Table 1, page 22, does. The diameter of the circle and the rise or height of the segment being known, the area of the segment may be found by the following rule:

Rule. Divide the height of the segment by the

TABLE 19

Areas of Segments of a Circle

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.2	.11182	.243	.14751	.286	.18542	.329	.22509
.201	.11262	.244	.14837	.287	.18633	.33	.22603
.202	.11343	.245	.14923	.288	.18723	.331	.22697
.203	.11423	.246	.15009	.289	.18814	.332	.22792
.204	.11504	.247	.15095	.29	.18905	.333	.22886
.205	.11584	.248	.15182	.291	.18996	.334	.22980
.206	.11665	.249	.15268	.292	.19086	.335	.23074
.207	.11746	.25	.15355	.293	.19177	.336	.23169
.208	.11827	.251	.15441	.294	.19268	.337	.23263
.209	.11908	.252	.15528	.295	.19360	.338	.23358
.21	.11990	.253	.15615	.296	.19451	.339	.23453
.211	.12071	.254	.15702	.297	.19542	.34	.23547
.212	.12153	.255	.15789	.298	.19634	.341	.23642
.213	.12235	.256	.15876	.299	.19725	.342	.23737
.214	.12317	.257	.15964	.3	.19817	.343	.23832
.215	.12399	.258	.16051	.301	.19908	.344	.23927
.216	.12481	.259	.16139	.302	.20000	.345	.24022
.217	.12563	.26	.16226	.303	.20092	.346	.24117
.218	.12646	.261	.16314	.304	.20184	.347	.24212
.219	.12729	.262	.16402	.305	.20276	.348	.24307
.22	.12811	.263	.16490	.306	.20368	.349	.24403
.221	.12894	.264	.16578	.307	.20460	.35	.24498
.222	.12977	.265	.16666	.308	.20553	.351	.24593
.223	.13060	.266	.16755	.309	.20645	.352	.24689
.224	.13144	.267	.16843	.31	.20738	.353	.24784
.225	.13227	.268	.16932	.311	.20830	.354	.24880
.226	.13311	.269	.17020	.312	.20923	.355	.24976
.227	.13395	.27	.17109	.313	.21015	.356	.25071
.228	.13478	.271	.17198	.314	.21108	.357	.25167
.229	.13562	.272	.17287	.315	.21201	.358	.25263
.23	.13646	.273	.17376	.316	.21294	.359	.25359
.231	.13731	.274	.17465	.317	.21387	.36	.25455
.232	.13815	.275	.17554	.318	.21480	.361	.25551
.233	.13900	.276	.17644	.319	.21573	.362	.25647
.234	.13984	.277	.17733	.32	.21667	.363	.25743
.235	.14069	.278	.17823	.321	.21760	.364	.25839
.236	.14154	.279	.17912	.322	.21853	.365	.25936
.237	.14239	.280	.18002	.323	.21947	.366	.26032
.238	.14324	.281	.18092	.324	.22040	.367	.26128
.239	.14409	.282	.18182	.325	.22134	.368	.26225
.24	.14494	.283	.18272	.326	.22228	.369	.26321
.241	.14580	.284	.18362	.327	.22322	.37	.26418
.242	.14666	.285	.18452	.328	.22415	.371	.26514

TABLE 19—*Continued*

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.372	.26611	.405	.29827	.438	.33086	.471	.36373
.373	.26708	.406	.29926	.439	.33185	.472	.36471
.374	.26805	.407	.30024	.44	.33284	.473	.36571
.375	.26901	.408	.30122	.441	.33384	.474	.36671
.376	.26998	.409	.30220	.442	.33483	.475	.36771
.377	.27095	.41	.30319	.443	.33582	.476	.26871
.378	.27192	.411	.30417	.444	.33682	.477	.36971
.379	.27289	.412	.30516	.445	.33781	.478	.37071
.38	.27386	.413	.30614	.446	.33880	.479	.37171
.381	.27483	.414	.30712	.447	.33980	.48	.37270
.382	.27580	.415	.30811	.448	.34079	.481	.37370
.383	.27678	.416	.30910	.449	.34179	.482	.37470
.384	.27775	.417	.31008	.45	.34278	.483	.37570
.385	.27872	.418	.31107	.451	.34378	.484	.37670
.386	.27969	.419	.31205	.452	.34477	.485	.37770
.387	.28067	.42	.31304	.453	.34577	.486	.37870
.388	.28164	.421	.31403	.454	.34676	.487	.37970
.389	.28262	.422	.31502	.455	.34776	.488	.38070
.39	.28359	.423	.31600	.456	.34876	.489	.38170
.391	.28457	.424	.31699	.457	.34975	.49	.38270
.392	.28554	.425	.31798	.458	.35075	.491	.38370
.393	.28652	.426	.31897	.459	.35175	.492	.38470
.394	.28750	.427	.31996	.46	.35274	.493	.38570
.395	.28848	.428	.32095	.461	.35374	.494	.38670
.396	.28945	.429	.32194	.462	.35474	.495	.38770
.397	.29043	.43	.32293	.463	.35573	.496	.38870
.398	.29141	.431	.32392	.464	.35673	.497	.38970
.399	.29239	.432	.32941	.465	.35773	.498	.39070
.4	.29337	.433	.32590	.466	.35873	.499	.39170
.401	.29435	.434	.32689	.467	.35972	.5	.39270
.402	.29533	.435	.32788	.468	.36072		
.403	.29631	.436	.32887	.469	.36172		
.404	.29729	.437	.32987	.47	.36272		

diameter of the circle. Then find the decimal opposite this ratio in the column headed "Area." Multiply this area by the square of the diameter. The result is the required area.

Example. Diameter of circle = 72 in. Height of segment = 25 in. $25 \div 72 = .347$, which will be found in the column headed "Ratio," and the area opposite this

is .24212. Then $.24212 \times 72 \times 72 = 1{,}255$ sq. in., area of segment.

A boiler is 66 in. in diameter, the working pressure is 100 lbs. per sq. in. The distance from the top row of tubes to the shell is 25 in. Required, the number of diagonal crow foot braces that will be needed to support the heads above the tubes, also the sectional area of each brace. The thickness of the heads is $\frac{5}{8}$ in. and the T.S. = 55,000 lbs. per sq. in.

Assume the head to be sufficiently strengthened by the flange for a distance of 2 in. from the shell, the diameter of the circle of which the segment above the tubes requires to be stayed is reduced by $2 + 2 = 4$ in. and will therefore be $66 - 4 = 62$ in. The rise or height of the segment above the tubes is $25 - 4 = 21$ in. Required, the area.* $21 \div 62 = .338$. Looking down the column headed "Ratio" in Table 19, area opposite .338 is .23358. Area of segment $= .23358 \times 62 \times 62 =$ 897.88 sq. in. The total pressure on this area will be $897.88 \times 100 = 89{,}788$ lbs.

Assume the braces to be made of $1\frac{1}{8}$ in. round steel having a T.S. of 50,000 lbs. per sq. in. and to be designed in such a manner as to allow for loss of material in drilling the rivet holes in the crow feet. Each brace will have a sectional area of .994 sq. in., and using 8 as a factor of safety, the strength or safe holding power of each stay may be found as follows: $.994 \times 50{,}000 \div 8 = 6{,}212$ lbs., and the number of stays required = 89,788 lbs. (total pressure) divided by 6,212 lbs. (strength of each stay) = 14 5, or in round numbers 15. If the stays are made of flat bars of steel the sectional area should equal that of the round stays, and the dimensions of the crow feet of all stays should

*See rule for Table 19.

be such as to retain the full sectional area of the body after the rivet holes are drilled.

Each stay is connected to the plate by two ⅞-in. rivets, having a T.S. of 55,000 lbs. per sq. in. and a shearing strength of 45,000 lbs. per sq. in. These rivets are capable of resisting a direct pull of 10,818 lbs., using 5 as a factor of safety; ascertained as follows: $2A \times 45{,}000 \div 5 = 10{,}818$ = strength of two rivets. They are also subjected to a crushing strain, and the resistance to this is $D \times C \div 5$, which expressed in figures is $.875 \times 90{,}000 \div 5 = 15{,}750$ lbs.

The proper spacing comes next, and is arrived at in the following manner:

Area to be stayed = 897.88 sq. in.

Number of stays = 15.

Area supported by each stay = $897.88 \div 15 = 59.8$ sq. in.

The square root of $59.8 = 7.75$ nearly, which is the distance in inches each way that the stays should be spaced, center to center.

If through stay rods are used in place of diagonal braces for staying the boiler under consideration, the number and diameter of the rods may be ascertained by the following method:

Assuming the heads to be supported by channel bars, as previously described, and that the stays are pitched 14 in. apart horizontally and 13 in. vertically, each stay would be required to support an area of $14 \times 13 = 182$ sq. in., and the number of stays would be $897.88 \div 182 = 4.9$, in round numbers 5. See Fig. 107. The pressure being 100 lbs. per sq. in., the total stress on each stay = $182 \times 100 = 18{,}200$ lbs. Assume the stay rods to be of soft steel having a T.S. of 50,000 lbs. per sq. in., and using a factor of safety of 8, the

sectional area required for each stay will be found as follows: $18,200 \times 8 \div 50,000 = 2.9$ sq. in., and the diameter will be found as follows: $2.9 \div .7854 = 3.69$, which is the square of the diameter, and the square root of $3.69 = 1.9$ in., or practically 2 in. The same methods of calculation are applicable to the staying of the heads below the tubes, also for stay bolts in fire box boilers.

Strength of Unstayed Surfaces. A simple rule for finding the bursting pressure of unstayed flat surfaces is that of Mr. Nichols, published in the "Locomotive," February, 1890, and quoted by Prof. Kent in his "Pocket-book." The rule is as follows: "Multiply the thickness of the plate in inches by ten times the tensile strength of the material used, and divide the product by the area of the head in square inches." Thus,

Diameter of head = 66 in.
Thickness of head = $\frac{5}{8}$ in.
Tensile strength = 55,000 lbs.
Area of head = 3,421 sq. in.

$\frac{5}{8} \times 55,000 \times 10 \div 3,421 = 100$, which is the number of pounds pressure per square inch under which the unstayed head would bulge.

If we use a factor of safety of 8, the safe working pressure would be $100 \div 8 = 12.5$ lbs. per sq. in., but as the strength of the unstayed head is at best an uncertain quantity it has not been considered in the foregoing calculations for bracing, except as regards that portion of it that is strengthened by the flange.

In all calculations for the strength of stayed surfaces, and especially where diagonal crow foot stays are used, the strength of the rivets connecting the stay to the flat plate must be carefully considered. A large factor of safety, never less than 8, should be used, and

the cross section of that portion of the foot of the stay through which the rivet holes are drilled should be large enough, after deducting the diameter of the hole, to equal the sectional area of the body of the stay.

Dished Heads. In boiler work where it is possible to use dished, or "bumped up" heads as they are sometimes called, this type of head is rapidly coming into use. Dished heads may be used in the construction of steam drums, also in many cases for dome-covers, thus obviating the necessity of bracing. The maximum depth of dish, as adopted by steel plate manufacturers April 4, 1901, is $\frac{1}{8}$ of the diameter of the head when flanged, and if the tensile strength and quality of the plate from which the heads are made are the same as those of the shell plate, the dished head becomes as strong as the shell, provided the head has the same thickness or is slightly thicker than the shell plate.

Welded Seams. A few boiler manufacturers have succeeded in making welded seams, thus dispensing with the time-honored custom of riveting the plates together. A good welded joint approaches more nearly to the full strength of the material than can possibly be attained by rivets, no matter how correctly designed the riveted joint may be. The weld also dispenses with the necessity of caulking, and a boiler having a perfectly smooth surface inside, such as would be afforded by welded seams, would certainly be much less liable to collect scale and sediment than would one with riveted joints. But in order to make a success of welded seams the material used must be of the best possible quality, and great care and skill are required in the work.

The Continental Iron Works of Brooklyn, New York, exhibited at the St. Louis World's Fair in 1904

a welded steel plate soda pulp digester without a single riveted joint. The dimensions of this vessel, which may be likened to a cylinder boiler without flues, were as follows: Thickness of plate, ¾ in.; diameter, 9 ft.; length, 43 feet. The heads were dished to the standard depth. The safe working pressure was 125 lbs. per sq. in. It appears not only possible, but probable, that the process of welding boiler joints may in time supplant the older custom of riveting.

CHAPTER II

CARE OF THE BOILER

Washing out the boiler—Duties of the boiler washer—How to prepare a boiler for washing—How to clean and inspect the inside of a boiler—Fusible plugs—Advantage of manholes, giving free access to top and bottom of boiler—Responsibility resting upon the boiler washer—Necessity of keeping water column clean—Scraping the flues—Fire cracks and how to deal with them—Firing up and how it should be done—Danger in too sudden heating up of a boiler—Advantages of filling a recently washed out boiler with warm water—Connecting with the main header and the safest method of procedure.

Washing Out. In order to get the best results from the burning of coal or any other fuel in a boiler furnace it is absolutely necessary to keep the boiler as clean as possible, both inside and outside. In large plants the boiler washer and his helper are detailed to look after this part of the work, and while the job is by no means a very desirable one, it is at the same time a very responsible one, and much depends upon the thoroughness with which the work is done. In small plants, consisting of one or two boilers, the engineer generally has to attend to the details of the work himself, and no matter whether the plant be large or small, the engineer in charge is the man above all others who should be most interested in seeing that thorough work is done, not only as a matter of safety, but for the sake of his reputation as an engineer. The boiler that is to be washed out should be allowed to gradually cool for ten or twelve hours. It will then be in a condition which will permit a man to go inside of it

and do effective work, and no boiler can be thoroughly cleaned and inspected unless the boiler washer does go inside.

These remarks apply, of course, to horizontal tubular or flue boilers and water tube boilers having drums large enough for a man to crawl into. Some types of internally fired boilers are provided with man-holes, but the majority of them have only hand-holes into which the hose for washing out may be inserted.

After the water has been allowed to run out, the first step in washing out a boiler is to remove all the loose mud and scale possible by means of a steel scraper fitted to a long handle and introduced through the man-hole in the bottom part of the head. This will prevent the scale from getting into the blow-off pipe and stopping the flow of the water used for washing the boiler. If there is a man-hole on top, the next thing in order is to take the hose in through it and give the sides of the shell and also the tubes a good cleaning.

Sometimes it happens that where an exhaust heater of the open type is used, oil will find its way into the boiler and, mixing with the mud, will form a thick pasty-like substance on the sides of the boiler along the water line. This should be carefully scraped off and removed, as any matter containing oil or grease is a very dangerous thing to have inside a boiler.

After cleaning the upper part of the boiler, it should be inspected for loose braces or rivets. This can best be accomplished by tapping the parts with a light hammer. A solid rivet will give a clear metallic sound, and a little practice will enable one to easily detect the sound of a loose brace or broken rivet.

Signs of corrosion or pitting of the shell along the

water line should also be carefully searched for. Fusible plugs, to be effective, must be kept clean, and the only opportunity for cleaning them is at the time of washing out the boiler. Therefore while working on the upper part of the boiler, attention should be given to the fusible plug. If it is one of the ordinary kind, screwed into the back head above the tubes, it should be taken out and cleaned and before replacing it the thread should be well coated with a mixture of cylinder oil and plumbago, which will prevent it from sticking. If the fusible plug is one of the type consisting of a brass tube extending from the top of the shell to the water level, the lower end of this tube should be cleaned of all mud or scale.

Having thus finished above the tubes, the mud and scale should again be scraped from the bottom, after which the hose should be inserted through the front man-hole that should be in every horizontal boiler.

Some authorities argue that a man-hole should not be cut in the bottom part of a boiler head, giving as their reason that it weakens the head, but the logic is not sound, for the reason that the man-hole can be reënforced in such a manner as to make it fully as strong as the solid sheet, and when we consider the great advantage of having a man-hole in the bottom, both as regards washing out and also for repairs, it is plain that it is really a necessity.

After washing out all the loose mud and scale that it is possible to get from the bottom, the boiler washer should next go inside and, with scrapers and tools made for the purpose, he should scrape and chip off all the scale that he can from the bottom, because there is where lies the greatest danger from burnt sheets caused by accumulations of scale preventing the

water from getting to the metal. Much good work may be accomplished in this way and no boiler washer should consider the job complete until he has gone through the boiler both top and bottom, and not only cleaned but inspected it. Any loose rivets, broken or loose braces, signs of corrosion or pitting should be at once reported to the chief engineer or superintendent.

It will thus be seen that great responsibility rests with the boiler washer, for the reason that he is the man that is in closest touch with the inside of the boiler, and it is due to the manner in which he does his work inside the boiler whether a defect is discovered and repaired in time or whether it is allowed to go until the result is often a grave disaster. The author desires to enter a plea for this hard-worked and too often underpaid craftsman, and hereby expresses the wish that his services were better appreciated.

The water column or combination should receive particular attention each time the boiler is washed out. The lower pipe leading to the boiler is liable to become clogged with scale, and if not cleaned regularly it is sure to cause trouble by preventing a free flow of the water from the boiler to the gauge glass.

If the boiler is of the horizontal tubular type, the tubes should be scraped inside, and with water tube boilers use the steam jet to blow the soot and ashes from between the tubes. Soot, in addition to choking the draft, is also a non-conductor of heat.

After the hand-hole and man-hole plates have been replaced the boiler may be filled with water to the proper level, and while this is being done it is in order to take a look into the furnace for any broken grates or accumulations of clinkers on the side walls or bridge wall. These clinkers should be chipped off, also the

bottom of the boiler should be swept clean of ashes and examined for any defects, such as fire cracks about the rivets most exposed to the heat. These cracks may often exist some time before being discovered unless a close inspection is made. They are small cracks radiating from the rivet holes outward past the rivet heads one-half to three-quarters of an inch, and are always liable to extend farther until they become a source of danger unless arrested in time. They may be closed up sometimes with the caulking tool, but if one should be found several inches in length, a hole should be drilled at the outer end of the crack and a rivet put in. This will generally stop it. Fire cracks occur in the girth seams only, and especially the seam nearest the fire.

It is essential that the bridge walls of horizontal boilers be kept in good repair, in order that as much fire brick surface as possible may be exposed to the heat. This will greatly aid combustion and prevent smoke.

Firing Up. After the boiler washer has completed his task the next thing in order is firing up, and in doing this if care and good judgment are not exercised there is danger of doing much damage to the boiler, especially if it has been filled with cold water. A very light fire should be started at first and kept that way until the water gets to the boiling point at least, after which the fire may be gradually increased until the steam gauge shows a few pounds pressure, when it will be safe to urge the fire still more. The bad effects resulting from the unequal expansion or contraction of the sheets and undue stress upon the rivets, all caused by rapid changes of the temperature of the boiler from hot to cold or vice versa, cannot be

guarded against too carefully, and they are liable to be brought about in two ways: first, by haste in cooling down a hot boiler that is to be washed out, and secondly, by starting a heavy fire under a cold boiler. That part of the boiler most exposed to the heat will become hot while other parts farthest removed from the fire may still be cold. Very often there is a difference of 150° or 200° in the temperature of different parts of the boiler for a time during the firing up process, and the same dangerous conditions may be caused also by blowing all the water out of a boiler while under a pressure of 15 or 20 lbs., as is the custom of some persons when preparing a boiler for washing out. Either custom cannot be too strongly condemned.

Sometimes a boiler is needed in a hurry after having been washed out, and in such an emergency it should be filled with warm water; in fact, it is better to always fill a boiler with warm water if it is possible to do so after washing out.

Connecting with the Main Header. When the gauge shows a pressure that is within 10 or 15 lbs. of being the same as that carried on the other boilers it should be watched closely, and when the pressure becomes the same as that in the main the connecting valve should be opened slightly, just sufficient to allow a light flow of steam through it, which can be easily detected by placing the ear near the valve chamber. This steam may be passing from the boiler to the header or vice versa, but whichever way it is going the valve should not be opened any farther until the pressure in the main pipe and in the boiler is equalized; when it will be found that the valve may be opened easily. While connecting the boiler the dampers should be closed.

Care should always be exercised in connecting a recently fired up boiler, and the engineer should be certain that the steam gauge and pop valve are in good working order. Otherwise there is liability of a serious accident occurring, either in breakage of the steam pipe, or what is still worse, a boiler explosion.

CHAPTER III

MECHANICAL STOKERS

Principles involved in the action of automatic stokers—Advantages and disadvantages attending their use—Classification and general description of stokers—Coal-handling machinery—Under-feed stokers—Mansfield chain grate stoker—Playford stoker—Vicars mechanical stoker—The Wilkinson stoker—Murphy stoker—Roney stoker—The American under-feed stoker—The Jones under-feed stoker—Outside furnaces—Conditions required in a boiler furnace to ensure good combustion—Hindrances to good combustion—Description of Burke outside furnace.

The principles governing the operation of mechanical or automatic stokers are in the main correct, viz., that the supply of coal and air is continuous and that provision is made for the regulation of the supply of fuel according to the demand upon the boiler for steam; also that the intermittent opening and closing of the furnace doors, as in hand firing, thereby admitting a large volume of cold air directly into the furnace on top of the fire, is avoided.

Mechanical stokers have within the last twelve years been largely adopted in the United States, especially in sections where bituminous coal is the principal fuel. The disadvantages attending their use are:

First, that the cost of properly installing them is so great that their use is practically prohibited to the small manufacturer.

Second, that in case of a sudden demand upon the boilers for more steam the automatic stoker cannot respond as promptly as in hand firing, although

this objection could no doubt be met by skillful handling.

Third, the extra cost for power to operate them, although this is probably offset by the diminished expense for labor required, as compared to hand firing.

There are many different types of mechanical stokers and automatic furnaces, but they may for convenience be grouped into four general classes. In class one the grate consists of an endless chain of short bars that travel in a horizontal direction over sprocket wheels, operated either by a small auxiliary engine or by power derived from an overhead line of shafting in front of the boilers.

In class two may be included stokers having grate bars somewhat after the ordinary type as to length and size, but having a continuous motion up and down or forward and back. This motion, though slight, serves to keep the fuel stirred and loosened, thus preventing the firing from becoming sluggish. The grate bars in this class of stokers are either horizontal or inclined at a slight angle, and their constant motion tends to gradually advance the coal from the front to the back end of the furnace.

Class three includes stokers having the grate bars steeply inclined. Slow motion is imparted to the grates, the coal being fed onto the upper end and forced forward as fast as required.

Class four includes an entirely different type of stoker, in that the fresh coal is supplied underneath the grates, and is pushed up through an opening left for the purpose midway of the furnace. The gases, on being distilled, immediately come in contact with the hot bed of coke on top and the result is good combustion. In this type of stoker steam is the active agent used for forcing the coal up into the furnace, either

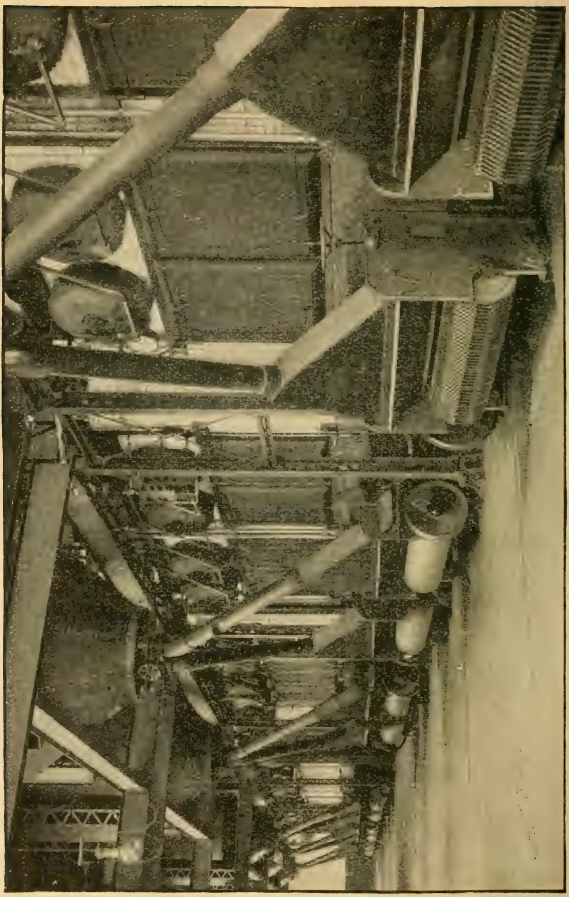


FIGURE 111.

by means of a long, slowly-revolving screw, as in the American stoker, or a steam ram, as with the Jones under-feed stoker. A forced draft is employed, and the air is blown into the furnace through tuyeres When these stokers are intelligently handled they give good results, especially with cheap bituminous coal. The clinker formed on the grate bars or dead plates is easily removed.

The coal is supplied to mechanical stokers either by being shoveled by hand into hoppers in front of and above the grates, or, as is the case in most of the large plants using them, it is elevated by machinery and deposited in chutes, through which it is fed to each boiler by gravity. Stokers of the chain grate variety are usually constructed so that they may be withdrawn from underneath the boiler in case repairs are necessary. The coal, either nut or screenings, is fed into a hopper in front of and above the level of the grate, and is slowly carried along towards the rear end. The ash drops from the grate as it passes over the sprocket wheel at the rear.

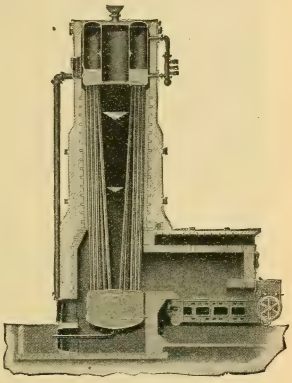


FIGURE 112.
CAHALL VERTICAL BOILER WITH CHAIN GRATE STOKER ATTACHED

Fig. 111 shows a battery of Babcock and Wilcox water tube boilers fitted with chain grate stokers. The

buckets for elevating the coal to bins overhead, from whence it is fed by gravity to the stokers, are not shown. These buckets or carriers may also be utilized for conveying the ashes from the boiler-room.

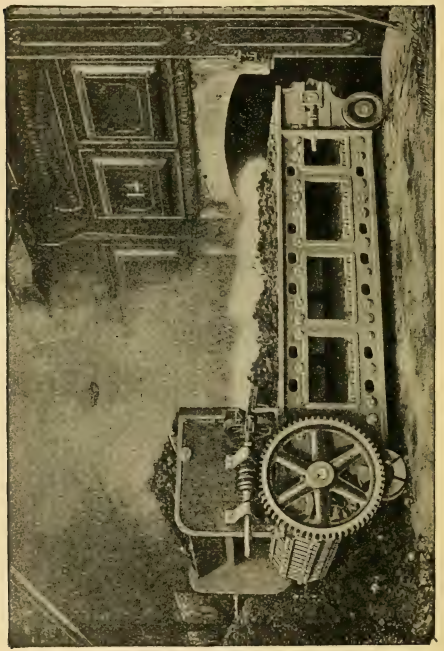


FIGURE 113.
MANSFIELD CHAIN GRATE STOKER, SHOWING HOW IT CAN BE WITHDRAWN FROM UNDER BOILER.

Fig. 112 is a sectional view of a vertical Cahall boiler with a Mansfield chain grate stoker, and Fig. 113 shows the same stoker withdrawn from the boiler.

The Coxe mechanical stoker operates upon the same

general principles as do those previously described, being of the chain grate type, but it has in addition a series of air chambers just underneath the upper traveling grate. These air chambers are made of sheet iron and are open at the top and provided with dampers for regulating the air pressure for different sections of the grate. The air blast is supplied by a fan. Another feature of this stoker is a water chamber for the bottom section of the grate to travel through on its return.

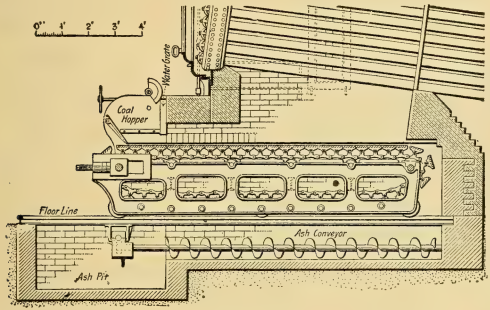


FIGURE 114.

The Playford stoker has wrought iron T bars extending across the furnace and attached to the traveling chains. These T bars carry the small cast iron sections composing the grate. A screw conveyor is also placed in the ash pit for the purpose of carrying the ashes from the rear to the front of the pit. Fig. 114 is a sectional view of the Playford stoker attached to a water tube boiler.

In class two may be included stokers having the grates inclined more or less. In some varieties the grates incline from front to rear, while in others they

are made to incline from the side walls towards the center line of the furnace.

In the Vicars mechanical stoker the grate bars are somewhat of the shape of the ordinary grate and lie in two tiers in a horizontal position. The lower or back tier next the bridge wall is stationary and is placed there for the purpose of catching what coal is carried over the ends of the upper or moving grate bars. These have a slow reciprocating motion which gradually moves the hot coke back towards the bridge wall The coal is fed from a hopper into two compartments, from which it is pushed by reciprocating plungers onto a coking plate and from thence it passes to the grate bars. The motion of these bars has several intermediate variations, from a state of rest to a movement of 3½ in. They have a simultaneous movement forward by which the fuel is advanced, but on the return movement the bars act at separate intervals. In this manner the fuel remains undisturbed by the return motion of the grates. Fig. 115 illustrates this stoker.

In the Wilkinson stoker, Fig. 116, the grate bars are hollow and are set at an angle of 20°, the inclination being from front to back. Each bar is stepped along its fire surface and on the rise is perforated with a long, narrow slot. A steam pipe extends along the front of the furnace and from this pipe small branch pipes lead into the ends of the grate bars, which latter are in fact a series of hollow trunks with their front ends open. When in operation a steam blast is admitted to each of the several trunk grate bars through the small branch pipes, and this blast induces an air current of more or less pressure, which finds an outlet through the narrow slots in the stepped fire

surface of the grates and directly into and through the burning mass of fuel. A slow reciprocating motion is imparted to the grates by means of cranks and links operated from an overhead shaft; see Fig. 117. These cranks are set alternately at 90° with each other, thus giving a forward movement to one-half of the grate bars while at the same time the other half is moving backward. In this manner the fuel is kept slowly moving down the inclined grates.

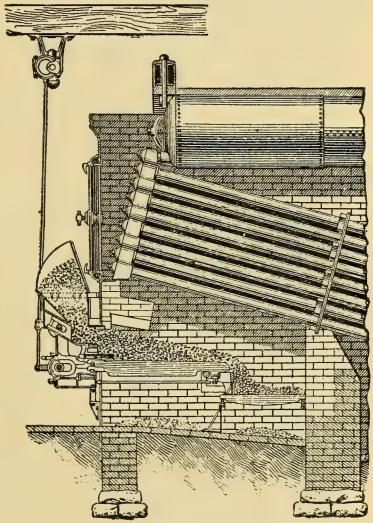


FIGURE 115.

The Murphy Automatic Furnace, a sectional view of which is shown in Fig. 118, has the grates inclined inwards from the side walls, while a fire brick arch is sprung from side to side to cover the entire length of the grate. The coal is shoveled or fed by carrier into the coal magazines, one on each side, as shown in the cut. If the furnace is placed directly under the boiler it necessitates putting these coal magazines within the side walls, but as the Murphy furnace is usually con-

structed at the present day as an outside furnace, the coal magazines are independent of the boiler walls.

The bottom of each magazine is used as a coking

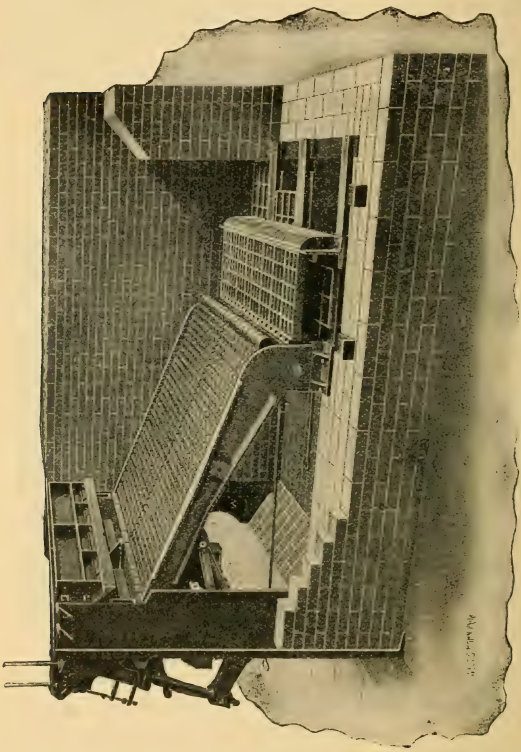


FIGURE 116.
FURNACE VIEW, WILKINSON STOKER.

plate, against which the upper ends of the inclined grates rest. On the central part of this plate is an inverted open box. This is termed the "stoker box,"

and it is moved back and forth across the face of the coking plate by means of a shaft with pinions that mesh into racks under each end of the box. By means

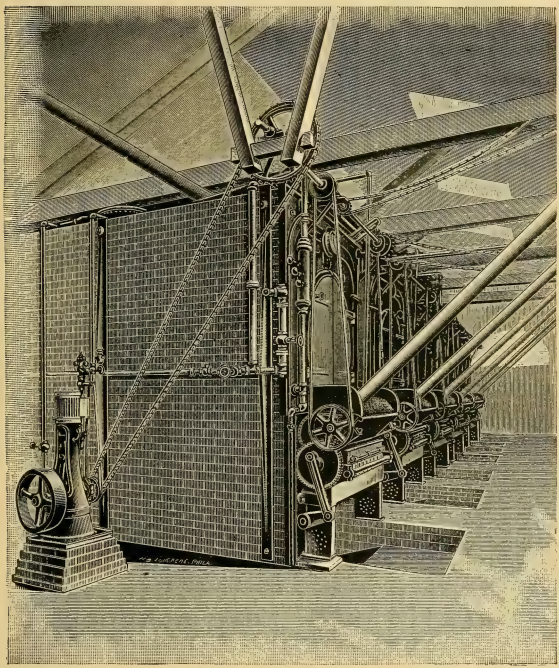


FIGURE 117. WILKINSON STOKER.

of this motion of the stoker boxes the coal is pushed forward to the edge of the coking plate and from thence it slowly passes down over the inclined grates

toward the center of the furnace. At this point the slowly rotating clinker breaker grinds the clinker and other refuse and deposits them in the ash pit.

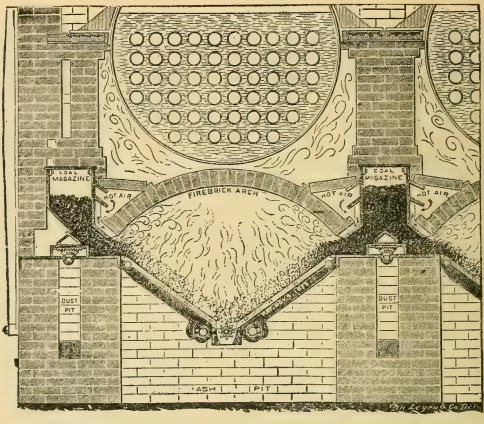


FIGURE 118. THE MURPHY AUTOMATIC FURNACE.

Above the coking plates are the "arch plates," upon which the bases of the fire brick arch rest. These plates are ribbed, the ribs being an inch apart, and, the arch resting upon these ribs, there is thus provided a series of air ducts by means of which the air, already heated by having been admitted in front and passed through the flues over the arch, is conducted into the furnace above the grates and comes directly in contact with the gases rising from the coking fuel. Air is also admitted under the coking plate and, passing up through the grates, serves to keep them cool and also furnishes the needed supply to the burning coke as it slowly moves down toward the center.

The fuel is aided in its downward movement by the constant motion of the grates, one grate of each pair being moved up and down by a rocker at the lower end.

Motion is imparted to the various moving parts of this furnace by means of a reciprocating bar extending across the outside of the entire front, and to which all the working parts are attached by links and levers. This bar is operated by a small engine at one side of the setting, the power required being about one horse-power per furnace.

The Roney stoker consists of a set of rocking stepped grate bars, inclined from the front towards the bridge wall. The angle of inclination is 37°. A dumping grate operated by hand is at the bottom of the incline for the purpose of receiving and discharging the clinker and ash. This dumping grate is divided into sections for convenience in handling.

The coal is fed onto the inclined grates from a hopper in front. The grate bars rock through an arc of 30°, assuming alternately the stepped and the inclined position. Fig. 119 is a sectional perspective view of this stoker and illustrates the working parts.

The grate bars receive their motion through the medium of a rocker bar and connecting rod. A shaft extending across the front of the stoker under the coal hopper carries an eccentric that gives motion to the connecting rod and also to the pusher in the coal hopper. This pusher, working back and forth, feeds the coal over the dead plate onto the grates, and its range of motion is regulated by a feed wheel from no stroke to full stroke, according to the demand for coal. The motion of the grate bars may also be regulated by

a sheath nut working on a long thread on the connecting rod. Each grate bar consists of two parts, viz., a cast iron web fitted with trunnions on each end that rest in seats in the side bearer and a fuel plate having the under side ribbed to allow a free circulation of air.

The fuel plate is bolted to the web and carries the

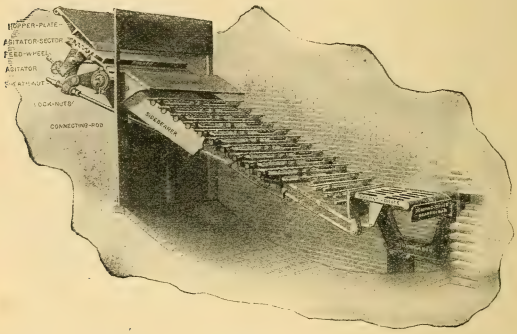


FIGURE 119.

SECTIONAL PERSPECTIVE OF THE RONEY MECHANICAL STOKER.

fuel. The grates lie in a horizontal position across the furnace in the form of steps, and ample provision is made for the admission of air through the slotted webs. A fire brick arch is also sprung across the furnace, covering the upper portion of the grate.

This arch, being heated to a high temperature, serves in a measure to partly coke the coal as it passes under it. Air is also admitted on top of the coal at the front. This air is heated by its passage through a perforated tile over the dead plate and adjoining the

fire brick arch. Fig. 120 shows the location of the arch and tile.

In mechanical stokers of the under-feed type the air is supplied by forced draft.

The American stoker consists of a horizontal conveyor pipe into which the coal is fed from a hopper. The diameter of this pipe depends upon the quantity of coal to be burned, and varies from 4½ in. for the smaller sizes up to 9 and 10 in. for the larger sized stokers. The length of the conveyor pipe for the

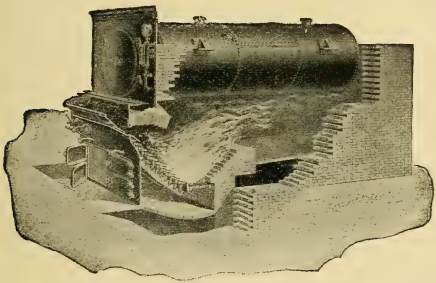


FIGURE 120.

standard 10-in. stoker is 72 in. Attached to the outer end of this conveyor pipe, and forming a part of it, is an iron box containing a reciprocating steam motor which, through the medium of a rocker arm and pawl and ratchet wheel, drives a screw conveyor shaft that slowly revolves within the pipe, thus forcing the coal forward and up through another box or trough, which latter is wholly within the furnace. Extending around the top edges of this box, and on a level with the grate bars, there is a series of tuyeres through which the air is forced.

These tuyeres, being at a high temperature, serve to heat the air in its passage through them, thus greatly

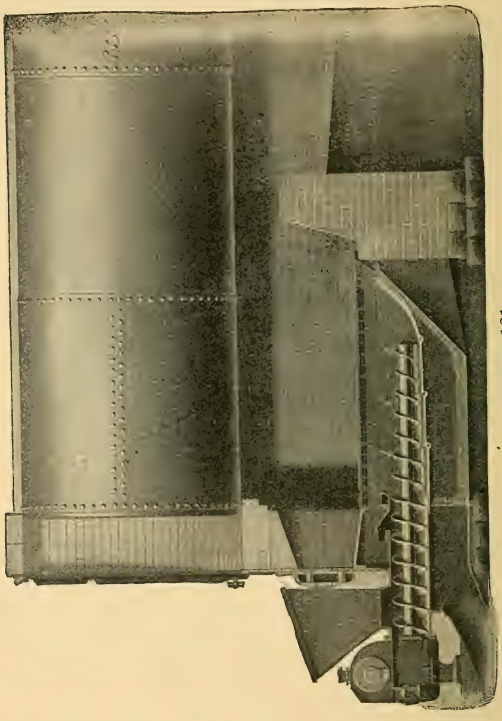


FIGURE 121.

TYPICAL SETTING OF AMERICAN STOKER UNDER A RETURN TUBULAR BOILER.

aiding combustion. Fig. 121 is a longitudinal sectional view of this stoker.

The speed of the screw conveyor is regulated by the hand throttle of the motor, according to the demand

for coal. With the 9-in. standard stoker from 350 to 1,200 lbs. of coal per hour may be burned. Fig. 122 is a view of the American stoker before being placed in position in the furnace.

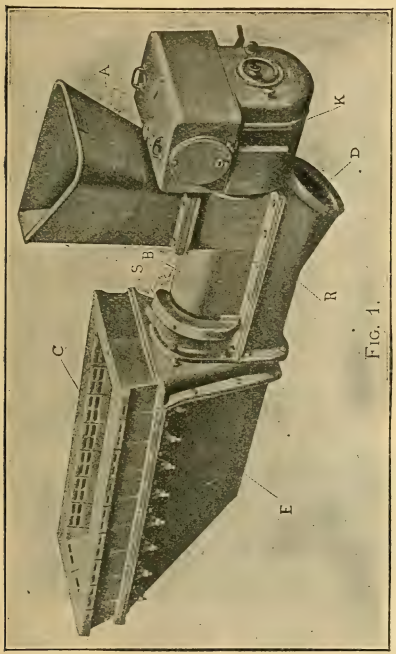


FIG. 1.

FIGURE 122. STANDARD 8 AND 9 INCH AMERICAN STOKERS.

A. Coal hopper.
B. Conveyor pipe.
C. Tuyeres for introducing air to the fuel.
D. Opening to wind-box for air connections.
E. Wind-box for supplying air to tuyeres.
K. Automatic steam motor for driving conveyor.
R. Air pipe to wind-box.
S. Gas ducts for returning volatile products from entering coal to furnace.

The air jets, passing out from the tuyeres in a horizontal direction, and from opposite sides, cut through the rounded bed of coal and the gases are thus ignited and consumed immediately after being distilled

from the coal, while the pressure of the coal rising from underneath forces the already coked fuel over the edges of the trough or box onto the grates which occupy the space between the side walls and the coal trough. The air is first delivered from the fan into the air box that surrounds the coal trough on three sides and from thence it passes to the tuyeres. If this stoker is properly handled very good results may be obtained by its use, but, like all other devices for burning coal under boilers, it is bad policy to endeavor to force it beyond its capacity.

In the Jones under-feed stoker the coal is pushed forward and up into the furnace through a cast iron retort or trough. The impelling force is a steam ram connected to the outer end of the retort, and the speed of the ram is regulated automatically by the steam pressure, or by hand as desired. The coal is supplied to the ram through a cast iron hopper having a capacity of 125 to 140 lbs.

Forced draft is also employed in this stoker, the air being conducted from the fan or blower through galvanized iron pipes into the closed ash pit, which really forms an air box, as the space on either side of the retort that is usually occupied by grate bars is in this case covered by solid cast iron dead plates upon which the coked fuel lies until it is consumed. These plates, being hot, serve to heat the air coming in contact with them in its passage to the cast iron tuyeres through which it passes to the bed of burning fuel in the retort. Air entirely surrounds the retort on the sides and back end, and is at a constant pressure in the ash pit, but can only pass into the furnace through the tuyeres, the jets of air cutting through the rounded heap of incandescent fuel from opposite sides and in a direction inclined upwards.

Coal is supplied to the hopper either by hand, or by mechanical means where the plant is fitted with coal-handling machinery. The opening through which it passes from the hopper to a position in front of the ram is 8×10 in. in size. Each charge of the steam

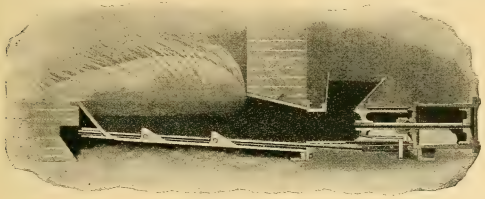


FIGURE 123.

ram carries forward 15 to 20 lbs. of coal. Connected to the ram and moving in conjunction with it is a long rod extending through the retort near the bottom. Upon this rod are carried shoes that act as auxiliary plungers and facilitate the movement of the coal.

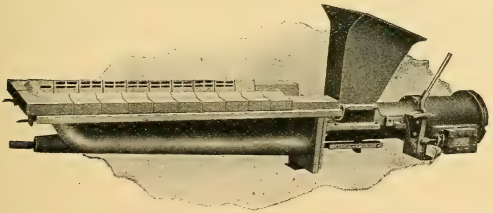


FIGURE 124.

Fig. 123 is a sectional view of the Jones stoker, showing the machine full of coal, with the ram ready to make a charge. Fig. 124 shows the stoker complete before being placed in the furnace.

It is claimed by the builders of under-feed stokers, and the claim appears to have good foundation, that by pushing the green coal up so as to meet the upper crust of glowing fuel the gases on being distilled immediately come in contact with and are consumed by the burning mass, and the formation of smoke is thus prevented. Both the Jones under-feed and the American stokers have proved to be very successful in the burning of the cheaper bituminous coals of the West. One feature tending to commend them is the fact that practically all of the coal is utilized, there being no waste caused by the slack coal or fine screenings dropping through the grate bars into the ash pit unconsumed.

A good substitute for the mechanical stoker is an outside furnace, by which is meant a boiler installation having the furnace in front of instead of underneath the boiler. One of the principal hindrances to good combustion in the ordinary type of boiler furnace is the fact that the temperature of the boiler shell or water tubes with which the gaseous products of combustion come in contact can never be higher than the temperature of the water contained within the boiler. This temperature ranges from 297° for steam at 50 lbs. gauge pressure, up to 407° for 255 lbs. pressure, while the temperature of the furnace, according to Dr. Thurston and other high authorities, ranges from 2,010° to 2,550°.

It is evident that perfect combustion does not take place until these high temperatures are reached. Each time the furnace is charged with fresh coal, especially if the boiler be hand-fired, a large volume of volatile gases is liberated but not consumed. If these gases are allowed to immediately come in contact with a

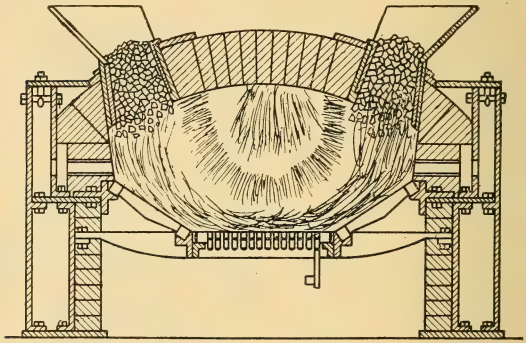
comparatively cool surface, as for instance the heating surface of the boiler, the result is a cooling of the gases, incomplete combustion and the formation of smoke and soot. If on the other hand the furnace is so constructed that these gaseous products first impinge against hot surfaces, such as fire brick arches or bafflers that have a temperature corresponding to that of the furnace, good combustion is assured. This condition is in a large degree attained by the use of outside furnaces that permit the construction of a fire brick arch to cover the entire grate surface.

Front View.
FIGURE 125.

The Burke furnace, patented by James V. Burke of Chicago, is a notable example of this type of furnace. It is applicable to any type of stationary boiler. Fig. 125 shows this furnace as applied to tubular boilers. It consists of a fire brick arch extending from 6 to 8 ft. outwards from the boiler front and of a width to correspond to the diameter of the boiler. The arch rests securely upon brick work inclosed in a well ventilated iron casing. There is practically no heat radiated from this furnace, all the heat generated

by it passing to the boiler. The central portion of the grate bars consists of shaking grates, while the side bars are stationary and inclined.

Fig. 126 is a sectional view and will serve to illustrate the construction of this furnace. The coal is fed through pockets on top on each side of the arch, the larger furnaces having two pockets on each side and the smaller sizes one. The doors in front are only



CROSS SECTION.
FIGURE 126.

opened for the purpose of cleaning fires or when first starting fires. The air is supplied by way of the ash pit, passing up through the grate bars. A portion of the air supply is also drawn through the ventilators and passes to the upper part of the furnace. The arch extends under the front end of the boiler 6 or 8 in., and there is a bridge wall about 4 ft. back from the front against which the gases from the furnace impinge.

There are 42 sq. ft. of grate surface in the larger

sizes, and 22 sq. ft. in the smaller size. Good combustion is attained in this furnace, owing to the fact that the gases as they are distilled from the coal come immediately in contact with the highly heated surface of the arch directly over the fire.

CHAPTER IV

THE STEAM TURBINE

The steam turbine—Lack of information concerning steam turbines—Points of difference between the turbine and the reciprocating engine—Kinetic energy in steam—Hero's steam turbine—Branca's steam turbine—Fundamental principles of the steam turbine—Types of steam turbines built in the United States—The Westinghouse-Parsons turbine—Theoretical velocity of steam exhausting into a vacuum—Relation of bucket speed to steam speed—Speed of the Westinghouse-Parsons turbine—Description of cylinder and blades—Relation of stationary to moving blades—Curvature of blades—Action of the steam within the turbine explained—Balancing pistons—Construction of bearings—A floating journal—Lubrication of bearings—Water seal packing—Speed regulation—Description and diagram of governor—Efficiency of steam turbines—Tests of Westinghouse-Parsons turbines.

Although the turbine principle of utilizing the energy in steam and converting it into useful work has been experimented upon for many years, it is only since the inauguration of the twentieth century that steam turbines have been brought to the front as efficient power producers.

There are to-day in this country four distinct types of steam turbines, each one of which has its own characteristic features distinguishing it from the others, but in each the kinetic energy and velocity of the expanding steam constitute the source of power.

Notwithstanding the fact that much has been said and written during the past four years regarding the steam turbine, the machine is to-day a mystery to thousands of engineers, not because they do not desire

information upon the subject, but because of a lack of opportunities for obtaining that information. The author therefore considers that a space devoted to this subject would no doubt be of benefit to his readers.

The piston of the reciprocating engine is driven back

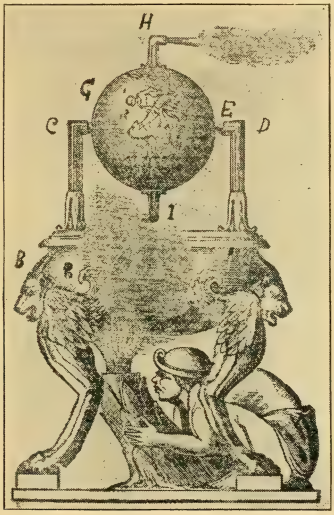


FIGURE 127.

and forth by the static expansive force of the steam, while in the steam turbine not only the expansive force is made to do work, but a still more important element is utilized, viz., the kinetic energy or heat energy latent in the steam and which manifests itself in the rapid vibratory motion of the particles of steam

expanding from a high to a lower pressure, and this motion the steam turbine transforms into work.

One of the earliest descriptions of a device for converting the power of steam into work was recorded by Hero, a learned writer who flourished in the city of Alexandria in Egypt, in the second century before Christ. Hero describes a machine called an Æolipile or "Ball of Æolus," illustrated in Fig. 127. B is the boiler under which a fire was made. G is a hollow

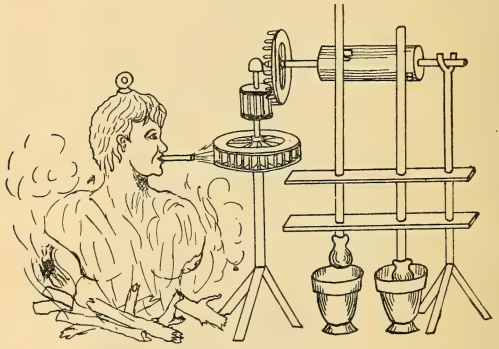


FIGURE 128.

metallic globe that revolved on trunnions C and D, one of which terminated in a pivot at E, while the other was hollow and conveyed the steam generated in the boiler B to the interior of the globe or ball, from which it escaped through the hollow bent tubes H and I, and the reaction of the escaping steam caused the globe to revolve. This was the first steam turbine, and it worked on the reaction principle.

Many centuries later, in the year A.D. 1629, Branca, an Italian, described an engine which marks a change

in the method of using the steam. Branca's engine consisted of a boiler A, Fig. 128, from which the steam issued through a straight pipe and impinged upon the vanes of a horizontal wheel carried upon a vertical shaft, causing it to revolve. This device was the germ of the impulse turbine, and these two principles, viz., reaction and impulse, either one or the other and sometimes a combination of both, are the fundamental principles upon which the successful steam turbines of the present age operate.

As previously stated, there are four types of steam turbines being manufactured in this country at present, viz.,

The Westinghouse-Parsons Turbine,
The General Electric Curtis Turbine,
The Hamilton-Holzwarth-Rateau Turbine, and
The De Laval Turbine.

Each will be taken up in its regular order and its distinctive theoretical features studied.

The Westinghouse-Parsons Steam Turbine is fundamentally based upon the invention of Mr. Charles A. Parsons, who, while experimenting with a reaction turbine constructed along the lines of Hero's engine, conceived the idea of combining the two principles, reaction and impulse, and also of causing the steam to flow in a general direction parallel with the shaft of the turbine. This principle of parallel flow is common to all four types of turbines, but is perhaps more prominent in the Westinghouse-Parsons and less so in the De Laval.

A cubic foot of steam under 100 lbs. pressure, if allowed to discharge into a vacuum of 28 in., would attain a theoretical velocity of 3,860 ft. per second and would exert 59,900 ft.-lbs. of energy. A law of turbo

mechanics specifies that in order to obtain the highest efficiency in the operation of turbines (whether water or steam) the relation between bucket speed and fluid speed (steam in this case) should be as follows:

For purely impulse wheels, bucket speed equals one-half of jet speed.

For reaction wheels, bucket speed equals jet speed.

Assuming the velocity of the jet of steam issuing from the nozzle to be 4,000 ft. per second, this would mean a peripheral speed of 2,000 ft. per second for an impulse wheel, and for a wheel 1 ft. in diameter the

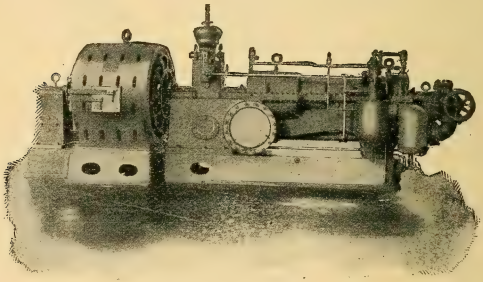


FIGURE 129.

speed would be 38,100 R. P. M. But such a speed is beyond the limits of strength of material.

As before stated, the Westinghouse-Parsons turbine operates on both impulse and reaction principles, and by a system of compounding, which will be explained later on, the peripheral velocity of the machine has been so reduced as to bring it within practical limits while at the same time the power value of the steam is utilized to a high degree of efficiency.

The speed of the Westinghouse-Parsons turbine

varies from about 750 R. P. M. for a 5,000 K. W. machine to 3,600 R. P. M. for a 400 K. W. turbine.

Fig. 129 is a general view of a 400 K. W. turbine generator unit. Fig. 130 shows a 600 H. P. machine with the upper half of the cylinder, or stator as it is termed, thrown back for inspection. Fig. 131 is a sectional view of a Westinghouse-Parsons turbine, and it will be noticed that there are three sections or drums, gradually increasing in diameter from the inlet A to

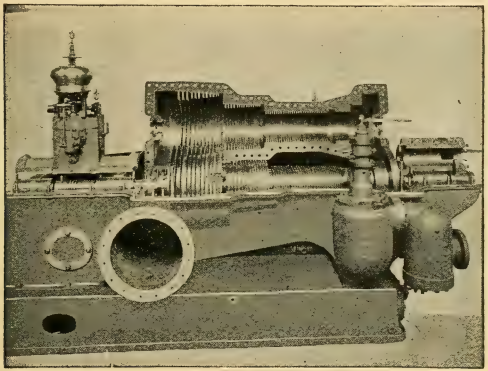


FIGURE 130.

the third and last group of blades. This arrangement may be likened in some measure to the triple compound reciprocating engine.

By reference to Fig. 130 it will be seen that the inside of the cylinder is studded with rows of small stationary blades and that the rotor or revolving part of the machine is also fitted with rows of small blades, similar in shape and dimensions to the stationary

blades. When the upper half of the cylinder is in position, each row of stationary blades fits in between two corresponding rows of moving blades. This arrangement may perhaps be better understood by reference to Fig. 132, which illustrates the relation of the stationary blades to the moving blades when in position, and also shows by the arrows the course of the steam and its change of direction caused by the stationary blades.

For the purpose of explanation the moving blades or

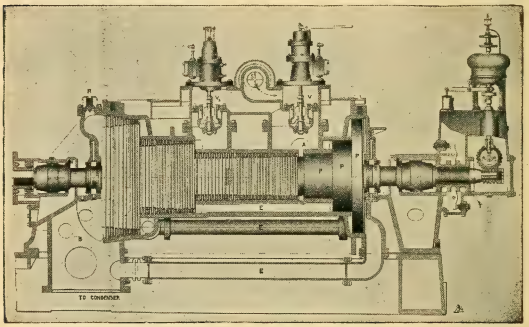


FIGURE 131.

vanes may be considered as small curved paddles projecting from the surface of the rotor, and there is a large number of them, as, for instance, taking a 400 K. W. machine, there are 16,095 moving blades and 14,978 stationary blades, a total of 31,073.

The stationary vanes, as previously explained, project from the inside surface of the cylinder. Both stationary and moving vanes are similar in shape, and are made of hard drawn material, and they are set into

their places and secured by a caulking process. The blades vary in size from ½ to 7 in. in length, according to where they are used. Referring to Fig. 130, it will be observed that the shortest blades are placed at what might be termed the steam end of each section or drum of the rotor and cylinder, and that their length gradually increases, corresponding with the increased volume of steam, until a mechanical limit is reached, when a new group of blades begins on a succeeding drum of larger diameter. Referring to Fig. 132, which is a sectional view of four rows of blades, it will

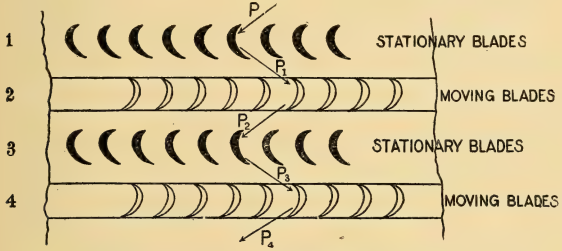


FIGURE 132.

be noticed that all the blades, whether stationary or moving, have the same curvature. Also that the curves are set opposite each other. The reason for this will be apparent as the diagram is studied. The steam at pressure P first comes in contact with row 1 of stationary blades. It expands through this row, and in expanding the pressure falls to P'.

The energy in the steam is converted into velocity, and it impinges upon row 2 of moving blades, driving them around in their course by impulse. A second expansion now occurs in row 2 and again the energy is converted into velocity, but this time the reaction of

the steam as it leaves the blades of row 2 also tends to impel them around in their course. The moving blades thus receive motion from two causes—the one due to the impulse of the steam striking them, and the other due to the reaction of the steam leaving them.

This cycle is repeated in rows 3 and 4, and so on throughout the length of the rotor until the exhaust end is reached.

It should be noted that the general direction taken by the steam in its passage through the turbine is in the form of a spiral or screw line about the rotor. The clearance between the blades as they stand in the rows is ⅛ in. for the smallest size blades and ½ in. for the larger ones, gradually increasing from the inlet to the exhaust. In the 5,000 K. W. machine the clearance at the exhaust end between the rows of blades is 1 in. It will thus be seen that there is ample mechanical clearance, also allowance for lateral motion for adjustment of the rotor, although this is very slight, as the rotor is balanced at all loads and pressures by the balancing pistons PPP, Fig. 131, to which reference is now made. These pistons revolve within the cylinder, but do not come in mechanical contact with it; consequently there is no friction. The diameter of each piston corresponds to the diameter of one of the three drums.

The steam entering the chamber A through valve V presses against the turbine blades and goes through doing work by reason of its velocity. It also presses equally in the opposite direction against the first piston P, and so the shaft or rotor has no end thrust. On leaving the first group of blades and striking the second group the pressure in either direction is again equalized by the balance port E allowing the steam to press against

the second balance piston P. The same event occurs at group three, the steam acting upon the third piston P.

The areas of the balancing pistons are such that, no matter what the load may be or what the steam pressure or exhaust pressure may be, the correct balance is maintained and there is practically no end thrust. Below is shown a pipe E connecting the back of the balancing pistons with the exhaust chamber. This arrangement is for the purpose of equalizing the pressure at this point with the pressure in the exhaust chamber B.

It might be thought that the blades, on account of their being so light and thin, would wear out very fast, but experience so far shows that they do not. This may be accounted for in two ways. First, the reduction of the velocity of the steam, the highest velocity in the Parsons turbine not exceeding 600 ft. a second; secondly, the light steam thrust on each blade, said to be equal to about 1 oz. avoirdupois. This is far within the bending strength of the material. A steam strainer is also placed in the admission port, to prevent all foreign substances from entering the turbine.

A rigid shaft and thrust or adjustment bearing accurately preserves the clearances, which are larger in this turbine than in other types, owing to the fact that the entire circumference of the turbine is constantly filled with working steam when in operation.

The bearings shown in Fig. 131 are constructed along lines differing from those of the ordinary reciprocating engine. The bearing proper is a gun metal sleeve that is prevented from turning by a loose-fitting dowel. Outside of this sleeve are three concentric tubes having a small clearance between them. This clearance is kept constantly filled with oil sup-

plied under light pressure, which permits a vibration of the inner shell or sleeve and at the same time tends to restrain or cushion it. This arrangement allows the shaft to revolve about its axis of gravity, instead of the geometrical axis, as would be the case if the bearing were of the ordinary construction. The journal is thus to a certain degree a floating journal, free to run slightly eccentric according as the shaft may happen to be out of balance.

A flexible coupling is provided, by means of which the power of the turbine is transmitted to the dynamo or other machine it is intended to run. The oil from all the bearings drains back into a reservoir, and from there it is forced up into a chamber, where it forms a static head, which gives a constant pressure of oil on all the bearings. A secondary valve is located at Vs, by means of which high pressure steam may be admitted to the steam space E on the same principle that high pressure steam is admitted to the low pressure cylinder of a compound engine. This valve opens automatically in cases of emergency, such as overload, failure of the condenser to work, etc.

The shaft, where it passes through either cylinder head, is packed with a water seal packing, consisting of a small paddle wheel attached to the shaft, which, through centrifugal action, maintains a static pressure of about 5 lbs. per sq. in. in the water seal, thus preventing all leakage while at the same time it is frictionless.

The speed of the Westinghouse-Parsons turbine is regulated by a fly ball governor constructed in such manner that a very slight movement of the balls serves to produce the required change in the supply of steam. Fig. 133 is a diagram of the governor

mechanism. The ball levers swing on knife edges instead of pins. The governor works both ways, that is to say, when the levers are oscillating about their mid position a head of steam corresponding to full load is being admitted to the turbine, and a movement from this point, either up or down, tends to increase or to decrease the supply of steam.

Referring to Fig. 133, B is a piston directly con-

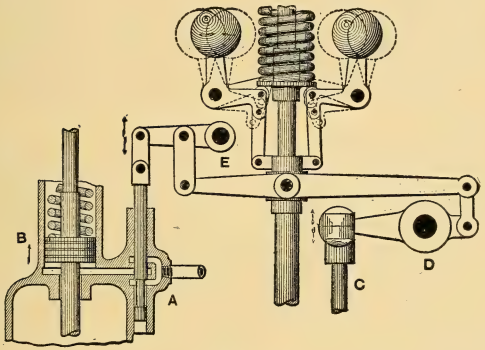


FIGURE 133.

nected to the admission valve. Steam is admitted to this piston under control of the pilot valve A, which has a slight but continuous reciprocating motion derived from the eccentric rod C, and the function of the governor is to vary the plane of oscillation of this valve, thus causing it to admit more or less steam to piston B. The admission valve, being actuated exclusively by piston B, is thus caused to remain open for a longer or shorter period of time, according to the load upon the turbine.

The vibrations of the admission valve, although very slight, are continuous and regular, about 165 per minute, and are transmitted primarily by means of an eccentric, the rod of which is shown at C, Fig. 133.

The governor sleeve is used as a floating fulcrum, and the points D and E are fixed. By means of this very ingenious device the steam is admitted to the turbine in puffs, either long or short, according to the demand for steam. At full load the puffs merge into an almost continuous blast. When the load has increased to the point where the valve is wide open continuously, a full head of steam is being admitted. Beyond this the secondary valve comes into action, thus keeping the speed up to normal.

The rotor requires perfect balancing to insure quiet running, but this is easily accomplished in the shop by means of a balancing machine used by the builders.

Steam turbines generally show higher efficiency in the use of steam than reciprocating engines do, and this fact is due to three leading causes. First, it is possible with the turbine to use highly superheated steam which, owing to the difficulties attending lubrication, could not be used in the reciprocating engine. Second, a larger proportion of the heat contained in the steam is converted into work, for the reason that the steam is allowed to expand to a much lower pressure and into a higher vacuum. In addition to this, the velocity of the expanding steam is utilized in a much higher degree in the turbine as compared with the reciprocating engine. Third, mechanical friction or lost work is reduced to the minimum. Under test a 400 K. W. Westinghouse-Parsons steam turbine, using steam at 150 lbs. initial pressure and superheated about 180°, consumed 11.17 lbs. of steam per Brake

horse power hour at full load. The speed was 3,550 R. P. M. and the vacuum was 28 in. With dry saturated steam the consumption was 13.5 lbs. per B. H. P. hour at full load, and 15.5 lbs. at one-half load.

A 1,000 K. W. machine, using steam of 150 lbs. pressure and superheated 140°, exhausting into a vacuum of 28 in., showed the very remarkable economy of 12.66 lbs. of steam per E. H. P. per hour.

A 1,500 K. W. Westinghouse-Parsons turbine, using dry saturated steam of 150 lbs. pressure with 27 in. vacuum, consumed 14.8 lbs. steam per E. H. P. hour at full load, and 17.2 lbs. at one-half load.

CHAPTER V

THE CURTIS STEAM TURBINE

The Curtis turbine an impulse and reaction machine—Admission of the steam—System of expanding nozzles—Ratio of expansion in four stage machine—Step bearing—Method of lubrication—Action of the steam in a two stage machine—Static force, and force of velocity compared—Speed regulation in Curtis turbine—Accomplished in first group of nozzles—How admission of steam is controlled—Velocity of the steam is constant, with light or full load—Two main sources of economy in the steam turbine—Efficiency tests of Curtis turbine.

In the Curtis turbine the heat energy in the steam is imparted to the wheel, both by impulse and reaction, but the method of admission differs from that of the Westinghouse-Parsons in that the steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs., from which it further expands to atmospheric pressure in passing through the wheels and intermediates. From the pressure in the first stage the steam again expands through the larger area

of the second stage nozzles to a pressure slightly greater than the condenser vacuum at the entrance to the second set of moving blades, against which it now impinges and passes through still doing work, due to velocity and mass.

From this stage the steam passes to the condenser. If the turbine is a four-stage machine and the initial pressure is 180 lbs., the pressure at the different stages would be distributed in about the following manner: Initial pressure, 180 lbs.; first stage, 50 lbs.; second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

The Curtis turbine is built by the General Electric Co. at their works in Schenectady, New York, and Lynn, Mass. The larger sizes are of the vertical type, and those of small capacity are horizontal.

Fig. 134 gives a general view of a 5,000 K. W. turbine and generator. The generator is shown at the top, while the turbine occupies the middle and lower section. A portion of the inlet steam pipe is shown, ending in one nozzle group at the side. There are three groups of initial nozzles, two of which are not shown. The revolving parts of this unit are set upon a vertical shaft, the diameter of the shaft corresponding to the size of the unit. For a machine having the capacity of the one illustrated by Fig. 134 the diameter of the shaft is 14 in.

The shaft is supported by and runs upon a step bearing at the bottom. This step bearing consists of two cylindrical cast iron plates, bearing upon each other and having a central recess between them into which lubricating oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath. A weighted accumulator is sometimes

installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as

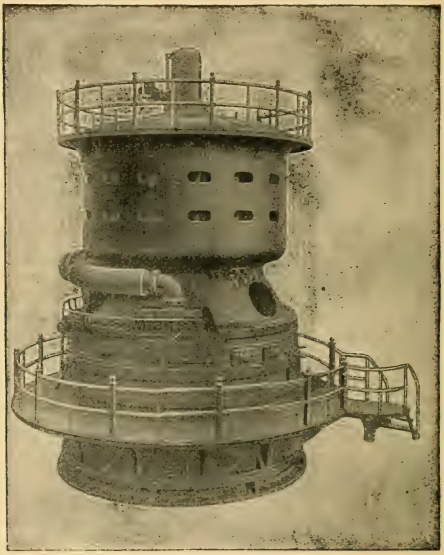


FIGURE 134.

5,000 K.W. CURTIS STEAM TURBINE DIRECT CONNECTED TO 5,000 K.W. THREE-PHASE ALTERNATING CURRENT GENERATOR.

the step bearing pumps have proven, after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings, one just above the step, one between the turbine and generator, and the other near

the top. These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum.

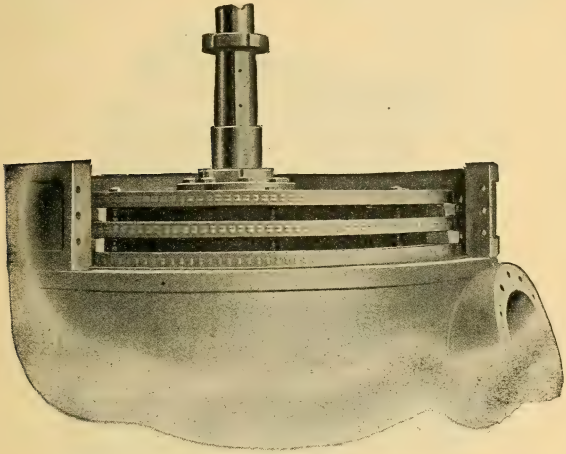
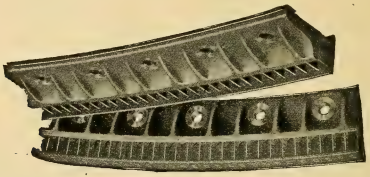


FIGURE 135.
500 K.W. CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION.

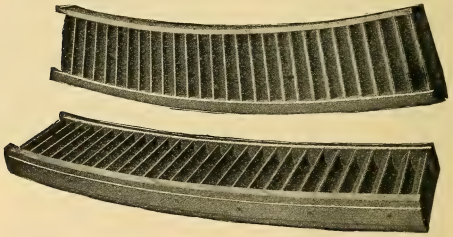
The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades, bolted to the inner walls of the cylinder or casing. As in the Westinghouse-Parsons

type, the function of the stationary blades is to give direction to the flow of steam.

Fig. 135 illustrates one stage of a 500 K. W. turbine in course of construction. It will be observed that there are three wheels, and that in the spaces between these wheels the stationary buckets or vanes are



REVOLVING BUCKETS FOR CURTIS STEAM TURBINE.



STATIONARY BUCKETS FOR CURTIS STEAM TURBINE.
FIGURE 136.

placed, being firmly bolted to the casing. Fig. 136 shows sections of both revolving and stationary buckets ready to be placed in position. The illustration in Fig. 135 shows the lower or last stage. The clearance between the revolving and stationary blades is from $\frac{1}{32}$ to $\frac{1}{16}$ in., thus reducing the wastage of steam to a very low percentage. The diameters of the

wheels vary according to the size of the turbine, that of a 5,000 K. W. machine being 13 ft.

Fig. 137 shows a nozzle diaphragm with its various openings, and it will be noted that the nozzles are set at an angle to the plane of revolution of the wheel.

Fig. 138 is a diagram of the nozzles, moving blades and stationary blades of a two-stage Curtis steam turbine. The steam enters the nozzle openings at the top, controlled by the valves shown, the regulation of which will be explained later on. In the cut Fig. 138 two of the valves are open, and the course of the steam through the first stage is indicated by the arrows.

FIGURE 137. NOZZLE.

After passing successively through the different sets of moving blades and stationary blades in the first stage, the steam passes into the second steam chest. The flow of steam from this chamber to the second stage of buckets is also controlled by valves, but the function of these valves is not in the line of speed regulation but for the purpose of limiting the pressure in the stage chambers, in a manner somewhat similar to the control of the receiver pressure in a two-cylinder or three-cylinder compound reciprocating engine.

The valves controlling the admission of steam to the second and later stages differ from those in the first group in that they partake more of the nature of slide

valves and may be operated either by hand or automatically; in fact, they require but very little regulation,

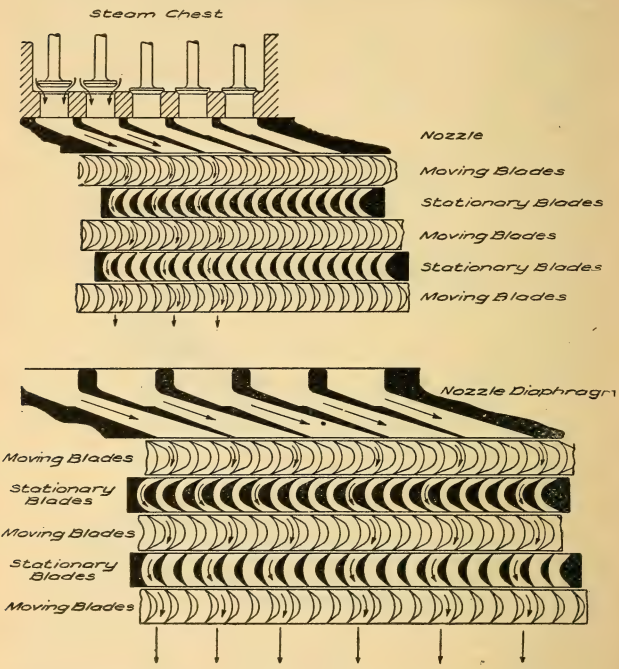


FIGURE 138.

DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE.

as the governing is always done by the live steam admission valves.

Action of the Steam in a Two-stage Machine. As previously stated, the steam first strikes the moving blades in the first stage of a two-stage machine at a

pressure of about 15 lbs. above atmospheric pressure, but with great velocity. From this wheel it passes to the set of stationary blades between it and the next lower wheel. These stationary blades change the direction of flow of the steam and cause it to impinge the buckets of the second wheel at the proper angle.

This cycle is repeated until the steam passes from the first stage into the receiving chamber or steam chest for the second stage. Its passage from this chamber into the second stage is controlled by valves, which, as before stated, are regulated either by hand or automatically. The course of the steam through the nozzles and blades of the second stage is clearly indicated by the arrows, and it will be noted that steam is passing through all the nozzles.

At this point it might be well to consider the question which no doubt arises in the mind of the student in his efforts to grasp the underlying principles in the action of the steam turbine. Why is it that the impingement of the steam, at so low a pressure, against the blades or buckets of the turbine, imparts such a large amount of energy to the shaft?

The answer is, because of velocity, and a good example of the manner in which velocity may be made to increase the capacity of an agent to do work is illustrated in the following way: Suppose that a man is standing within arm's length of a heavy plate glass window and that he holds in his hand an iron ball weighing 10 lbs. Suppose the man should place the ball against the glass and press the same there with all the energy he is capable of exerting. He would make very little, if any, impression upon the glass. But suppose that he should walk away from the window a distance of 20 ft. and then exert the same

amount of energy in throwing the ball against the glass, a different result would ensue. The velocity with which the ball would impinge the surface of the glass would no doubt ruin the window. Now, notwithstanding the fact that weight, energy and time involved were exactly the same in both instances, yet a much larger amount of work was performed in the latter case, owing to the added force imparted to the ball by the velocity with which it impinged against the glass.

Speed Regulation. The governing of speed is accomplished in the first set of nozzles, and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. This governor, by a very slight movement, imparts motion to levers, which in turn work the valve mechanism. The admission of steam to the nozzles is controlled by piston valves, which are actuated by steam from small pilot valves which are in turn under the control of the governor. Fig. 139 shows the form of governor for a 5,000 K. W. turbine, and Fig. 140 shows the electrically operated admission valves for one set of nozzles.

Speed regulation is effected by varying the number of nozzles in flow, that is, for light loads fewer nozzles are open and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

The Curtis Steam Turbine is the result of the investigations and experiments of Mr. C. G. Curtis of New

York, and while retaining the advantage of the expanding nozzle of De Laval, it at the same time utilizes the energy acquired by velocity, by causing the steam to

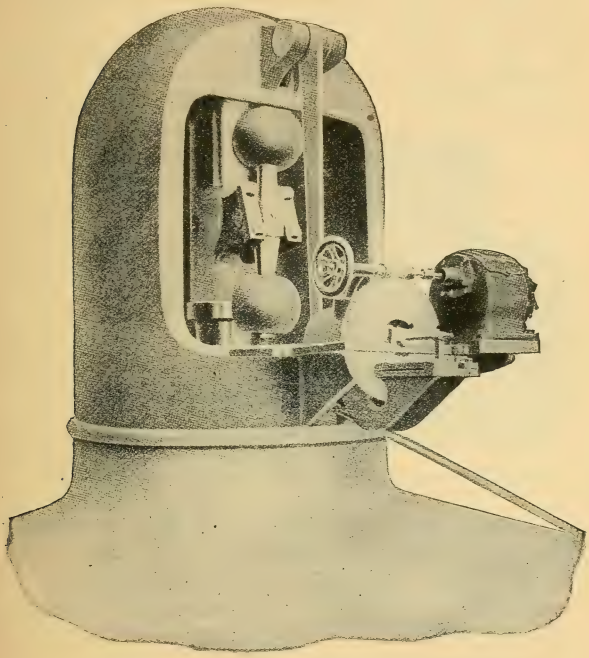


FIGURE 139. GOVERNOR FOR 5,000 K.W. TURBINE.

impinge the moving buckets of two or more wheels in succession. A portion of this velocity force is given up in the first stage, and another portion in the second stage, and this process is repeated, the steam in each

case being first caused to expand in divergent nozzles and thus acquire new velocity before it is allowed to impinge the moving blades of the next lower stage. The pressure in each succeeding stage of expansion becomes lower and lower, until finally vacuum is reached.

As previously stated, two of the main sources of economy that the steam turbine possesses in a much higher degree than does the reciprocating engine are: first, its adaptability for using superheated steam, and second, the possibility of maintaining a higher degree of vacuum.

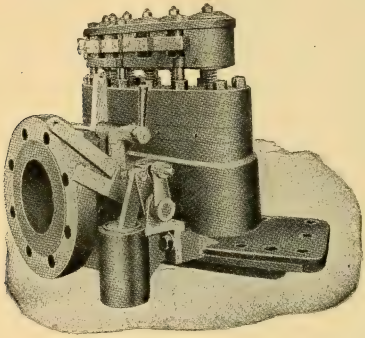


FIGURE 140. ELECTRICALLY OPERATED VALVE.

The efficiency shown by the steam turbine is certainly remarkable, and one peculiar feature regarding the machine is, that its efficiency is not affected by variations in load to the same degree as is the efficiency of the reciprocating engine.

A 600 K. W. Curtis turbine operating at 1,500 R. P. M., with steam at 140 lbs. gauge pressure and 28.5 in. vacuum, showed a steam consumption as follows, steam superheated 150°:

At full load, 12.5 lbs. per E. H. P. per hour.

At half load, 13.25 lbs. per E. H. P. per hour.

At one-sixth load, 16.2 lbs. per E. H. P. per hour.

And at one-third overload, 12.4 lbs. per E. H. P. per hour.

This would seem to indicate that the efficiency of the steam turbine increases with overload, at least up to a certain point.

In another test of a Curtis turbine, using dry saturated steam of 145 lbs. gauge pressure, the steam consumption at full load was 14.76 lbs. per E. H. P. hour, and at half load the rate was 15.95 lbs. per E. H. P. hour. The same machine using steam superheated 150° showed a steam consumption of 13.27 lbs. per E. H. P.hour, at full load.

A Curtis turbine carrying a commercial load on a 15-hour run showed an average coal consumption as follows; the turbine was operated with one boiler independently of the other boilers in the battery, and the steam was not superheated: Coal consumed per E. H. P. hour, 1.86 lbs.

The highest type of modern reciprocating engine, triple expansion, condensing, having steam jacketed cylinders, shows a coal consumption of 1.5 to 2 lbs. per H. P. per hour, assuming the evaporation to be 8 lbs. water per pound of coal.

CHAPTER VI

THE HAMILTON-HOLZWARTH STEAM TURBINE

The Hamilton-Holzwarth steam turbine—Points of difference between it and the Westinghouse-Parsons—Small clearances necessary—Stationary discs and guide vanes—Running wheels—Expansion of the steam and where it occurs—Action of the steam within the machine—Various stages in high and low pressure casings—Curvature of vanes—Purpose of stationary discs—Thrust ball bearings—Description of the governor and regulating mechanism—Close regulation—Method of changing speed while running.

This turbine resembles the Westinghouse-Parsons turbine in some respects, prominent of which is that it is a full stroke turbine, that is, that the steam flows through it in one continuous belt or veil in screw line, the general direction being parallel with the shaft. But, unlike the Parsons type, the steam in the Hamilton-Holzwarth turbine is made to do its work only by impulse, and not by impulse and reaction combined. It might thus be termed an action turbine.

The Hamilton-Holzwarth steam turbine is based upon and has been developed from the designs of Prof. Rateau, and is being manufactured in this country by the Hooven-Owens-Rentschler Co. of Hamilton, Ohio. It is horizontal and placed upon a rigid bed plate of the box pattern. All steam, oil and water pipes are within and beneath this bed plate, as are also the steam inlet valve and the regulating and by-pass valves.

The smaller sizes of this turbine are built in a single casing or cylinder, but for units of 750 kilowatts and

larger the revolving element is divided into two parts, high and low pressure.

There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

The clearance allowed is as small as practical, as it is in this clearance between the revolving hub and the circumference of the bore of the stationary disc that the leakage losses occur. It should be noted that between each two stationary discs there is located a running wheel, and that the clearance between the running vanes and the stationary vanes is made as slight as is consistent with safe practice; otherwise leakage would occur here also, and besides this there would be a distortion of the steam jet and entrainment of the surrounding atmosphere, resulting in a rapid decline in economy if the clearance between the stationary and moving elements was not reduced to as small a fraction as possible.

As before stated, the stationary discs are firmly secured to the interior walls of the casing. At intervals on the outside periphery of these discs are located the stationary or guide vanes. These are made of drop forged steel. They are set in a groove on the outside edge of the disc and fastened with rivets. Both disc and vanes are then ground, giving the vanes the profile that they should have for the most efficient expansion of the steam. After this is done a steel ring is shrunk on the outside periphery of the vanes and the steam

channels in the disc. These discs are then placed in the grooves in the casing at regular intervals, and in the spaces between them are the running wheels.

The casing is divided into an upper and lower half. The running wheels are built with a cast steel hub having a steel disc riveted on to each side, thus forming a circumferential ring space into which the running vanes are riveted. A thin steel band or rim is tied on the outer edge of the vanes, thus forming an outer wall to the steam channels and confining the steam within the vanes. These vanes are also milled on both edges, on the influx and efflux side of the wheel, thus forming them to the shape corresponding to the theoretical diagram.

The running vanes conform in section somewhat to the Parsons type, but the action of the steam upon them and also within the stationary vanes is different. The expansion of the steam and consequent development of velocity takes place entirely within the stationary vanes, which also change the direction of flow of the steam and distribute it in the proper manner to the vanes of the running wheels, which, according to the claims of the makers, the steam enters and leaves at the same pressure, thus allowing the wheel to revolve in a uniform pressure.

Fig. 141 shows a general view of the Hamilton-Holzwarth turbine, and the action of the steam within the machine may be described as follows: After leaving the steam separator that is located beneath the bed plate, the steam passes through the inlet or throttle valve, the stem of which extends up through the floor near the high pressure casing and is protected by a floor stand and equipped with a hand wheel, shown in Fig. 141. The steam now passes through the regulat-

ing valve, which will be described later on. From this valve it is led through a curved pipe to the front head of the high pressure casing or cylinder. In this head is a ring channel into which the steam enters, and from whence it flows through the first set of stationary vanes. In these vanes the first stage of expansion occurs, the velocity of the flow is accelerated, and the direction of flow is changed by the curve of the vanes in such manner that the steam impinges the vanes of the first running wheel at the proper angle and in a full cylindrical belt, imparting by impulse a portion of its energy to the wheel. Passing through the vanes of this wheel, the steam immediately enters the vanes of the second stationary disc, which are larger in area than those of the first, and here occurs the second stage of expansion, another acceleration of velocity, and also the proper change in direction, and the steam leaves this distributer and impinges the vanes of the second

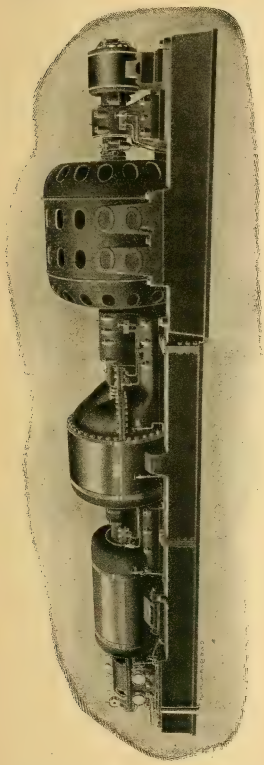


FIGURE 141.

running wheel. This cycle is repeated throughout the several stages of the turbine, a certain percentage of the heat energy in the steam being imparted by impulse to each wheel and thence to the turbine shaft. From the last running wheel the steam is led through receiver pipes to the front head of the low-pressure cylinder, or, if there is but one cylinder, directly to the condenser or the atmosphere.

In the low-pressure casing, which is larger in diameter than the high-pressure the steam is distributed in the same manner as it is in the high-pressure casing. There is, however, in the front head of the low-pressure casing an additional nozzle through which live steam may be admitted in case of overload. The design of this nozzle is such that the live steam entering and passing through it and controlled by the governor exerts no back pressure on the steam coming from the receiver, but, on the contrary, its action is similar to the action of an injector, that is, it tends to suck the low-pressure steam through the first set of stationary vanes of the low-pressure turbine.

The first stationary disc of the low-pressure turbine has guide vanes all around its circumference, so that the steam enters the turbine in a full cylindrical belt, interrupted only by the guide vanes. To provide for the increasing volume as the steam expands in its course through the turbine, the areas of the passages through the distributers and running vanes must be progressively enlarged. The gradual increase in the dimensions of the stationary vanes permits the steam to expand within them, thus tending to maintain its velocity, while at the same time the vanes guide the steam under such a small angle that the force with which it impinges the vanes of the next running wheel

is as effective as possible. The curvature of the vanes is such that the steam while passing through them will increase its velocity in a ratio corresponding to its operation.

The purpose of the stationary discs is, as has been stated, to distribute the steam to the running wheels. They also take the back pressure of the steam as it impinges the vanes of the running wheels, thus in a sense acting as balancing pistons.

In all steam turbines one of the main requisites for a quiet-running machine is that the revolving element or rotor shall be perfectly balanced. The rotary body of the Hamilton-Holzwarth turbine consists of a plurality of running wheels, each one of which is balanced by itself before being placed upon the shaft. All the bearings are lubricated in a thorough manner by oil forced up into the bottom bushing or shell under slight pressure. Flexible couplings are used between the high and low-pressure shafts, and for connecting the turbine shaft to the generator shaft or other shaft to be driven. By means of the thrust ball-bearing on the exhaust end of the turbine the shaft may be adjusted in an axial direction in such manner as to accurately preserve the desired position of the running wheels with relation to the stationary discs.

The governor is of the spring and weight type, adapted to high speed, and is designed especially for turbine governing. It is directly driven by the turbine shaft, revolving with the same angular velocity. Its action is as follows: Two discs keyed to the shaft drive, by means of rollers, two weights sliding along a cross bar placed at right angles through the shaft and compressing two springs against two nuts on the cross bar. Every movement of the weights, caused by

increasing or decreasing the angular velocity of the turbine shaft, is transmitted by means of levers to a sleeve which actuates the regulating mechanism. These levers are balanced so that no back pressure is exerted upon the weights. The whole governor is closed in by the discs, one on each side, and a steel ring secured by concentric recesses to the discs. In order to decrease the friction within the governor and regulating mechanism, thrust ball-bearings and frictionless roller-bearings are used.

As previously stated, the regulating valve is located beneath the bed plate. One side of it is connected by a curved pipe with the front head of the high-pressure cylinder and the other side is connected with the inlet valve. The regulating valve is of the double-seated poppet valve type. Valves and valve seats are made of tough cast steel, to avoid corrosion as much as possible, and the valve body is made of cast iron.

Immediately below the regulating valve and forming a part of it in one steam chamber is located the by-pass regulating valve. Thus the use of a second stuffing box for the stem of this valve is avoided. The function of this valve is to control the volume of the live steam supply that flows directly to the by-pass nozzles in the front head of the low-pressure casing. This valve is also a double-seated poppet valve.

The main regulating valve is not actuated directly by the governor, but by means of the regulating mechanism. The construction and operation of this regulating mechanism is as follows: The stem of the regulating valve is driven by means of bevel gears by a shaft that is supported in frictionless roller-bearings. On this shaft there is a friction wheel that the governor can slide across the face of a continuously revolving

friction disc by means of its sleeve and bell crank lever. This revolving disc is keyed to a solid shaft which is driven by a coupling from a hollow shaft. This hollow shaft is driven by the turbine shaft through the medium of a worm gear. The solid shaft, with the continuously revolving friction disc, can be slightly shifted by the governor sleeve so that the two friction discs come into contact when the sleeve moves, that is, when the angular velocity changes. If this change is relatively great, the sleeve will draw the periodically revolving friction disc far from the center of the always revolving one, and this disc will quickly drive the stem of the regulating valve and the flow of steam will thus be regulated. As soon as the angular velocity falls below a certain percentage of the normal speed, the driving friction disc is drawn back by the governor, the regulating valve remains open and the whole regulating mechanism rests or stops, although the shaft is still running.

Should the angular velocity of the shaft reach a point 2.5 per cent higher than normal, the governor will shut down the turbine. If an accident should happen to the governor, due to imperfect material or breaking or weakening of the springs, the result would be a shut-down of the turbine.

In order to change the speed of the turbine while running, which might be necessary in order to run the machine parallel with another prime mover, a spring balance is provided, attached to the bell crank lever of the regulating mechanism. The hand wheel of this spring balance is outside of the pedestal for regulating mechanism and near the floor-stand and hand wheel. With this spring balance the speed of the turbine may be changed 5 per cent either way from normal.

All the bearings of the unit are thoroughly lubricated with oil forced under pressure by the oil pump driven by means of worm-gearing by the turbine itself. After flowing through the bearings the oil is passed through a filter and from thence to the oil tank located within the bed plate, from whence it is taken by the oil pump. All revolving parts are enclosed, and the principal part of the regulating mechanism operates in a bath of oil.

CHAPTER VII

DE LAVAL STEAM TURBINE

De Laval steam turbine—High velocity—The De Laval divergent nozzle—Adiabatic expansion of steam within nozzle—Conversion of static energy into kinetic—Form of De Laval wheel—Speed of buckets—Speed of turbine shaft, and how it is reduced—Construction of the wheel—Number of buckets required—Number of nozzles—Gear and flexible shaft—Description of governor—Vacuum valve—Operation of governor—Efficiency tests—Steam consumption—Cross section of wheel showing correct design—Table of sizes, giving speed and weight.

The De Laval steam turbine, the invention of Carl De Laval of Sweden, is noted for the simplicity of its construction and the high speed of the wheel—10,000 to 30,000 R. P. M. The difficulties attending such high velocities are, however, overcome by the long, flexible shaft and the ball and socket type of bearings, which allow of a slight flexure of the shaft in order that the wheel may revolve about its center of gravity, rather than the geometrical center or center of position. All high speed parts of the machine are made of forged nickel steel of great tensile strength. But one of the most striking features of this turbine is the diverging nozzle, also the invention of De Laval.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet

of steam issuing from the nozzle is equal to the amount of energy that would be developed if an equal volume of steam were allowed to adiabatically expand behind the piston of a reciprocating engine, a condition, how-

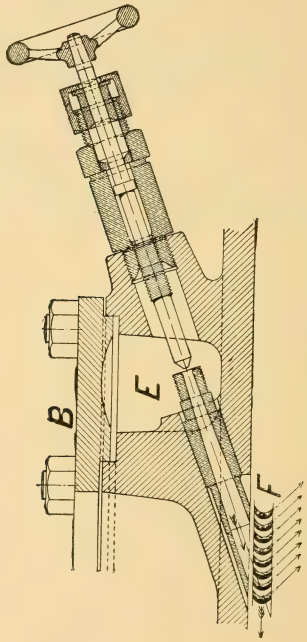


FIGURE 142. DE LAVAL NOZZLE

ever, which for obvious reasons has never yet been attained in practice with the reciprocating engine. But with the divergent nozzle the conditions are different.

Referring to Fig. 142, a continuous volume of steam

at maximum pressure is entering the nozzle at E, and, passing through it, expands to minimum pressure at F, the temperature of the nozzle being at the same time constant and equal to the temperature of the passing steam. The principles of the De Laval expanding nozzle are in fact more or less prominent in all steam

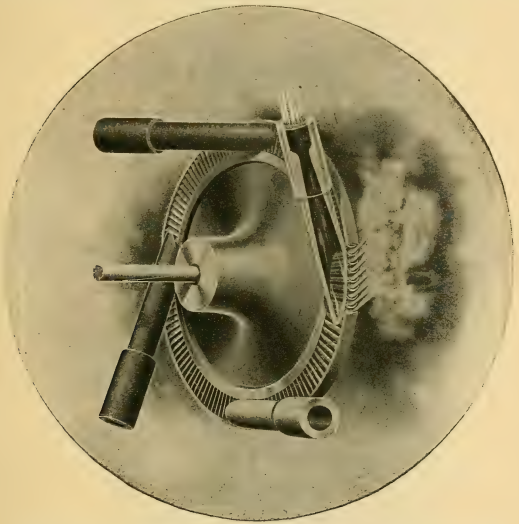


FIGURE 143. THE DE LAVAL TURBINE WHEEL AND NOZZLES.

turbines. The facilities for converting heat into work are increased by its use, and the losses by radiation and cooling influences are greatly lessened.

The De Laval steam turbine is termed by its builders a high-speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as

has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or

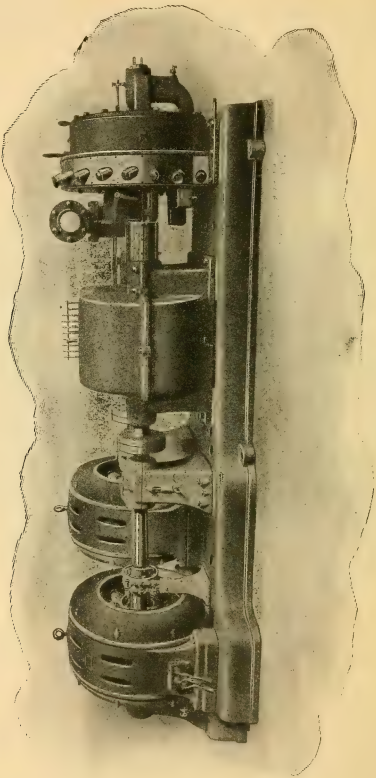


FIGURE 144.

guide blades, the augular position of the nozzles giving direction to the jet. Fig. 143 shows the form of wheel

and the nozzles. The nozzles are placed at an angle of 20° to the plane of motion of the buckets, and the course of the steam is shown by the illustration.

The heat energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 ft. per second. To attain the maximum of efficiency the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 ft. per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 ft. per second.

Fig. 144 shows a De Laval steam turbine motor of 300 H. P., which is the largest size built up to the present time, its use having been confined chiefly to light work.

The turbine illustrated in Fig. 144 is shown directly connected to a 200 K. W. two-phase alternator. The steam and exhaust connections are plainly shown, as also the nozzle valves projecting from the turbine casing. The speed of the turbine wheel and shaft is entirely too high for most practical purposes, and it is reduced by a pair of very perfectly cut spiral gears, usually made 10 to 1. These gear wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90° to each other. This arrangement insures smooth running and at the same time checks any tendency of the shaft towards end thrust, thus dispensing with a thrust bearing.

The working parts of the machine are clearly illus-

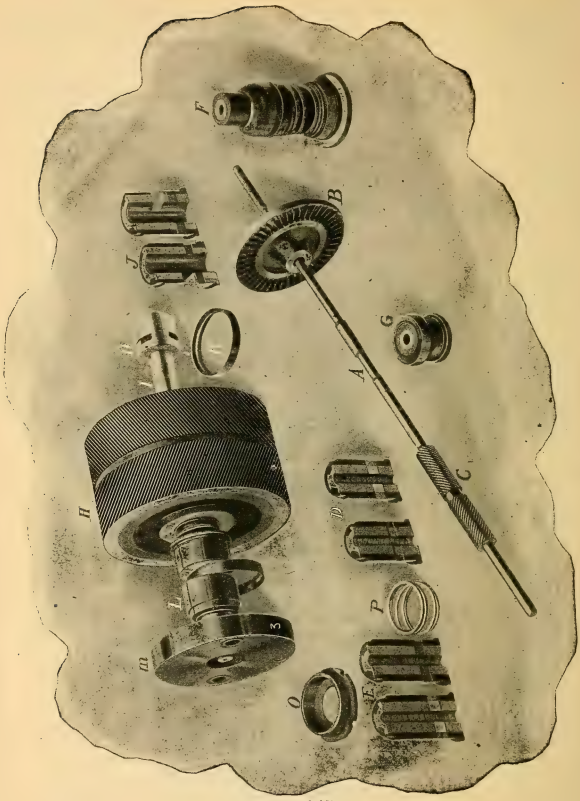


FIGURE 145.

trated in Fig. 145, and a fairly good conception of the assembling of the various members, and especially the reducing gears, may be had by reference to Fig. 146,

which shows a 110 H. P. turbine and rotary pump with the upper half of the gear case and field frame removed for purposes of inspection. The slender shaft is seen projecting from the center of the turbine case, and upon this shaft are shown the small pinions meshing into the large spiral gears upon the two pump shafts.

Referring to Fig. 145, A is the turbine shaft, B is the turbine wheel, and C is the pinion. As the turbine wheel is by far the most important element, it will be taken up first. It is made of forged nickel steel, and it is claimed by the builders, the De Laval Steam Turbine Co. of Trenton, New Jersey, that it will withstand more than double the normal speed before showing any signs of distress. A clear idea of the construction of the wheel and buckets may be had by reference to Fig. 143. The number of buckets varies according to the capacity of the machine. There are about 350 buckets on a 300 H. P. wheel. The buckets are drop forged and made with a bulb shank fitted in slots milled in the rim of the wheel.

Fig. 147 is a sectional plan of a 30 H. P. turbine connected to a single dynamo, and Fig. 148 is a sectional elevation of the same.

The steam, after passing the governor valve C, Fig. 148, enters the steam chamber D, Fig. 147, from whence it is distributed to the various nozzles. The number of these nozzles depends upon the size of the machine, ranging from one to fifteen. They are generally fitted with shut-off valves (see Fig. 144) by which one or more nozzles can be cut out when the load is light. This renders it possible to use steam at boiler pressure, no matter how small the volume required for the load. This is a matter of great importance, especially where the load varies con-

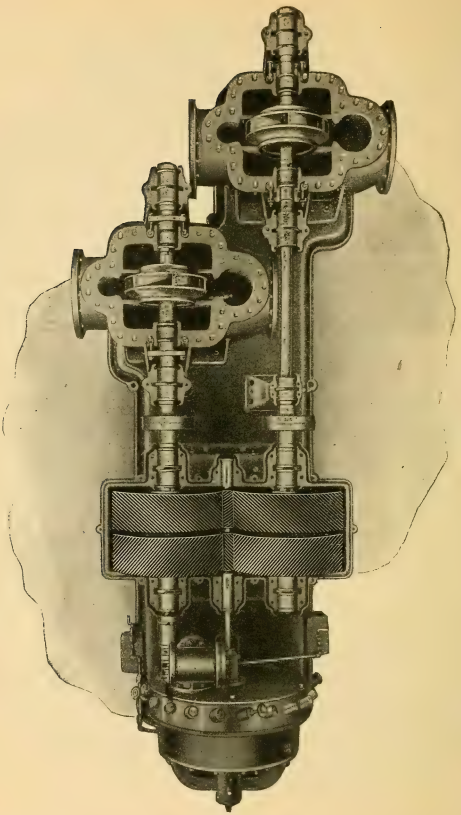


FIGURE 146.

siderably, as, for instance, there are plants in which during certain hours of the day a 300 H. P. machine may be taxed to its utmost capacity and during certain

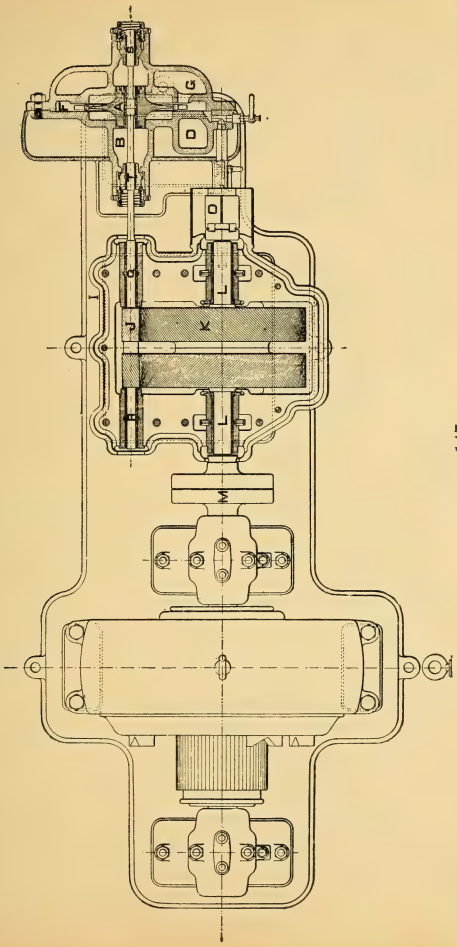


FIGURE 147.

other hours the load on the same machine may drop to 50 H. P. In such cases the number of nozzles in action may be reduced by closing the shut-off valves until the required volume of steam is admitted to the wheel. This adds to the economy of the machine. After passing through the nozzles, the steam, as elsewhere explained, is now completely expanded, and in impinging on the buckets its kinetic energy is transferred to the turbine wheel. Leaving the buckets, the steam now passes into the exhaust chamber G, Fig. 147, and out through the exhaust opening H, Fig. 148, to the condenser or atmosphere as the case may be.

The gear is mounted and enclosed in the gear case I, Fig. 147. J is the pinion made solid with the flexible shaft and engaging the gear wheel K. This latter is forced upon the shaft L, which, with couplings M, connects to the dynamo or is extended for other transmission.

O, Fig. 148, is the governor held with a taper shank in the end of the shaft L, and by means of the bell crank P operates the governor valve C. The flexible shaft is supported in three bearings, Fig. 147. Q and R are the pinion bearings and S is the main shaft bearing which carries the greater part of the weight of the wheel. This bearing is self-aligning, being held to its seat by the spring and cap shown.

T, Fig. 147, is the flexible bearing, being entirely free to oscillate with the shaft. Its only purpose is to prevent the escape of steam when running non-condensing, or the admission of air to the wheel case when running condensing. The flexible shaft is made very slender, as will be observed by comparing its size with that of the rotary pump shaft in Fig. 146. It is by means of this slender, flexible shaft that the dangerous feature

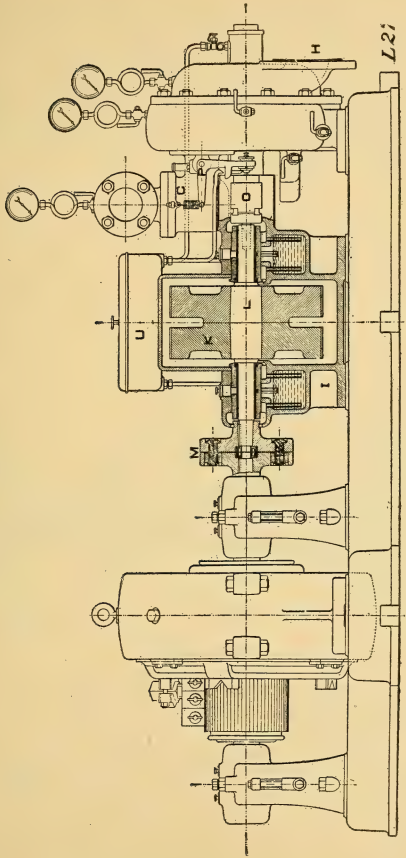


FIGURE 148.

of the enormously high speed of this turbine is eliminated.

The governor is of the centrifugal type, although differing greatly in detail from the ordinary fly ball governor, as will be seen by reference to Fig. 149. It is connected directly to the end of the gear wheel shaft. Two weights B are pivoted on knife edges A with

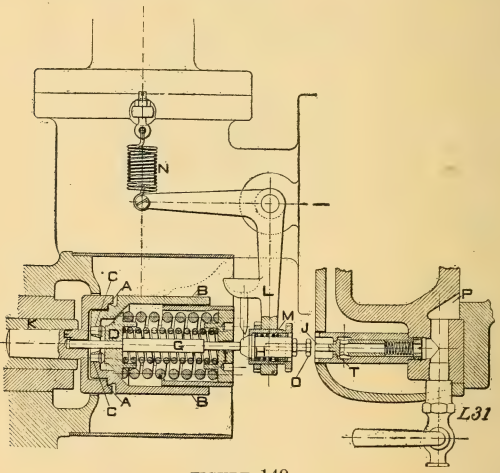


FIGURE 149.

hardened pins C, bearing on the spring seat D. E is the governor body fitted in the end of the gear wheel shaft K and has seats milled for the knife edges A. It is afterwards reduced in diameter to pass inside of the weights and its outer end is threaded to receive the adjusting nut I, by means of which the tension of the spring, and through this the speed of the turbine, is adjusted. When the speed accelerates, the weights,

affected by centrifugal force, tend to spread apart, and pressing on the spring seat at D push the governor pin G to the right, thus actuating the bell crank L and cutting off a part of the flow of steam.

It has been found necessary with this turbine, when running condensing, to introduce a valve termed a vacuum valve, also controlled by the governor, as it has been found that the governor valve alone is unable to hold the speed of the machine within the desired limit. The function of the vacuum valve is as follows: The governor pin G actuates the plunger H, which is screwed into the bell crank L, but without moving the plunger relative to said crank. This is on account of the spring M being stiffer than the spring N, whose function is to keep the governor valve open and the plunger H in contact with the governor pin. When a large portion of the load is suddenly thrown off, the governor opens, pushing the bell crank in the direction of the vacuum valve T. This closes the governor valve, which is entirely shut off when the bell crank is pushed so far that the screw O barely touches the vacuum valve stem J. Should this not check the speed sufficiently, the plunger H is pushed forward in the now stationary bell crank and the vacuum valve is opened, thus allowing the air to rush into the space P in which the turbine wheel revolves, and the speed is immediately checked.

The main shaft and dynamo bearings are ring oiling. The high-speed bearings on the turbine shaft are fed by gravity from an oil reservoir, and the drip oil is collected in the base and may be filtered and used over again.

The fact that the steam is used in but a single stage or set of buckets and then allowed to pass into the

exhaust chamber might appear at first thought to be a great loss of kinetic energy, but, as has been previously stated, the static energy in the steam as it enters the nozzles is converted into kinetic energy by its passage through the divergent nozzles, and the result is a greatly increased volume of steam leaving the nozzles at a tremendous velocity, but at a greatly reduced

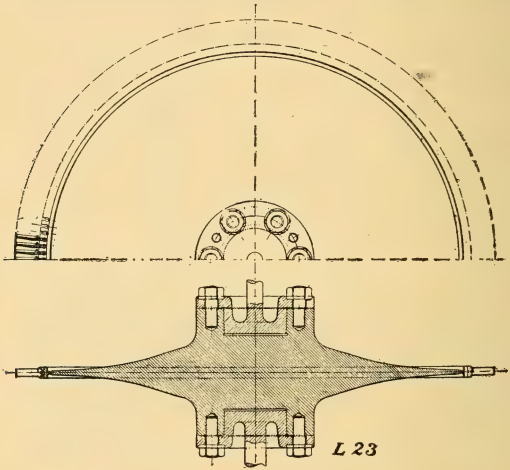


FIGURE 150.

pressure — practically exhaust pressure — impinging against the buckets of the turbine wheel and thus causing it to revolve.

Efficiency tests of the De Laval turbine show a high economy in steam consumption, as, for instance, a test made by Messrs. Dean and Main of Boston, Mass, on a 300 H P. turbine, using saturated steam at about 200 lbs. pressure per sq. in. and developing 333 Brake

H. P., showed a steam consumption of 15.17 lbs. per B. H. P., and the same machine, when supplied with superheated steam and carrying a load of 352 B. H. P., consumed but 13.94 lbs. per B. H. P. These results compare most favorably with those of the highest type of reciprocating engines.

Fig. 150 shows a cross section of a 300 H. P. De Laval wheel, showing the design necessary for withstanding the high centrifugal stress to which these wheels are subjected. All De Laval wheels are tested to withstand the centrifugal stress of twice their normal velocity without showing signs of fatigue.

The following table gives the sizes and weights of some of these turbines, together with revolutions per minute of the turbine shaft and the main shaft.

Horse Power	Revolutions Turbine Shaft	Revolutions Main Shaft	Approximate Weight Pounds
5	30,000	3,000	330
10	24,000	2,400	650
20	20,000	2,000	1,250
75	16,400	1,500	5,000
110	13,000	1,200	8,000
225	11,060	900	15,000
300	10,500	900	20,000

CHAPTER VIII

DISPOSAL OF THE EXHAUST STEAM OF STEAM TURBINES

Advantages of exhausting into a condenser—Possible to maintain higher vacuum in condenser of a turbine than with reciprocating engine—Surface condensers—Bulkley injector condenser—Steam turbine condensing apparatus at St. Louis Exposition, 1904—Dry air pump—Gain in economy from high vacuum—Cost of operating auxiliaries—Necessity of excluding all air from condensing system—Ways in which air may be entrained—Comparative efficiency of turbines and reciprocating engines—Percentage of saving per each inch increase in vacuum above 25 inches—Advantages of superheating the steam—Outlook for future of steam turbines.

As in the case of the reciprocating engine, the highest efficiency in the operation of the steam turbine is obtained by allowing the exhaust steam to pass into a condenser, and experience has demonstrated that it is possible to maintain a higher vacuum in the condenser of a turbine than in that of a reciprocating engine. This is due, no doubt, to the fact that in the turbine the steam is expanded down to a much lower pressure than is possible with the reciprocating engine.

The condensing apparatus used in connection with steam turbines may consist of any one of the modern improved systems, and as no cylinder oil is used within the cylinder of the turbine, the water of condensation may be returned to the boilers as feed water. If the condensing water is foul or contains matter that would be injurious to the boilers, a surface condenser should be used. If the water of condensation is not to be used

in the boilers, the jet system may be employed. Another type of condenser that is being successfully used with steam turbines is the Bulkley injector condenser.

Among the steam turbines that were on exhibition at the St. Louis exposition in 1904 the Westinghouse-Parsons and the General Electric Curtis turbines were each equipped with Worthington surface condensers, fitted with improved auxiliary apparatus consisting of dry vacuum pumps, either horizontal of the well-known Worthington type, or rotative motor-driven, a hot well pump, and a pump for disposing of the condensed steam from the exhaust system. The two latter pumps were of the Worthington centrifugal type. The Hamilton-Holzwarth turbine was equipped with a Smith-Vaile surface condenser, fitted with a duplex double-acting air pump, a compound condensing circulating pump, and a rotative dry vacuum pump, motor-driven. The vacuum maintained was high, 28 to 28.5 in.

As an instance of the great gain in economy effected by the use of the condenser in connection with the steam turbine, a 750 K. W. Westinghouse-Parsons turbine, using steam of 150 lbs. pressure not superheated and exhausting into a vacuum of 28 in., showed a steam consumption of 13.77 lbs. per B. H. P. per hour, while the same machine operating non-condensing consumed 28.26 lbs. of steam per B. H. P. hour. Practically the same percentage in economy effected by condensing the exhaust applies to the other types of steam turbines.

With reference to the relative cost of operating the several auxiliaries necessary to a complete condensing outfit, the highest authorities on the subject place the

power consumption of these auxiliaries at from 2 to 7 per cent of the total turbine output of power. A portion of this is regained by the use of an open heater for the feed water, into which the exhaust steam from the auxiliaries may pass, thus heating the feed water and returning a part of the heat to the boilers.

A prime requisite to the maintenance of high vacuum, with the resultant economy in the operation of the condensing apparatus, is that all entrained air must be excluded from the condenser. There are various ways in which it is possible for air to find its way into the condensing system. For instance, there may be an improperly packed gland, or there may be slight leaks in the piping, or the air may be introduced with the condensing water. This air should be removed before it reaches the condenser, and it may be accomplished by means of the "dry" air pump.

This dry air pump is different from the ordinary air pump that is used in connection with most condensing systems. The dry air pump handles no water, the cylinder being lubricated with oil in the same manner as the steam cylinder. The clearances also are made as small as possible. These pumps are built either in one or two stages.

A barometric or a jet condenser may be used, or a surface condenser. The latter type lessens the danger of entrained air, besides rendering it possible to return the condensed steam, which is pure distilled water, to the boilers along with the feed water, a thing very much to be desired in localities where the water used for feeding the boilers is impregnated with carbonate of lime or other scale-forming ingredients.

In comparing the efficiency of the reciprocating engine and the steam turbine it is not to be inferred

that reciprocating engines would not give better results at high vacuum than they do at the usual rate of 25 to 26 in., but to reach and maintain the higher vacuum of 28 to 28.5 in. with the reciprocating engine would necessitate much larger sizes of the low-pressure cylinder, as also the valves and exhaust pipes, in order to handle the greatly increased volume of steam at the low pressure demanded by high vacuum.

The steam turbine expands its working steam to within 1 in. of the vacuum existing in the condenser, that is, if there is a vacuum of 28 in. in the condenser there will be 27 in. of vacuum in the exhaust end of the turbine cylinder. On the other hand, there is usually a difference of 4 or 5 in. (2 to 2.5 lbs.) between the mean back pressure in the cylinder of a reciprocating condensing engine and the absolute back pressure in the condenser.

It therefore appears that the gain in economy per inch increase of vacuum above 25 in. is much larger with the turbine than it is with the reciprocating engine. Mr. J. R. Bibbins estimates this gain to be as follows: between 25 and 28 in. there is a gain of 3½ to 4 per cent per inch of increase, and at 28 in. 5 per cent. These results have been obtained by means of exhaustive tests conducted by Mr. Bibbins. Other high authorities on the steam turbine all agree as to the great advantages to be derived by incurring the extra expense of erecting a condensing plant that is capable of maintaining the high vacuum necessary to high efficiency.

Another method by which the steam consumption of the turbine may be materially decreased and a great gain in economy effected is by superheating the steam. The amount of superheat usually specified is 100°, and

the apparatus employed for producing it may be easily mounted in the path of the waste gases. The steam may thus be superheated without extra cost in fuel, and an increase of 8 to 10 per cent in economy effected. The independent superheater requires extra fuel and labor, and the gain in this case is doubtful, but there can be no question as to the wisdom of utilizing the waste flue gases for superheating the steam.

As previously stated, the steam turbine is peculiarly adapted for the use of highly superheated steam and high vacuum, and in these two particulars it excels the reciprocating engine At the present time many large plants are equipped with turbine engines that are giving the best of results, and the outlook for the future employment of this type of power producer is certainly very promising.

PART III

Electricity for Engineers

Electricity for Engineers

CHAPTER I

The Electric Current—The Ampere—The Volt—The Ohm—The Watt—Divided Circuits.

The Electric Current. All electrical phenomena with which we have to deal are produced through the medium of the electric current. This current flows only in a conductor of electricity. Among the most noteworthy of the conductors are the various metals; the most useful, and in fact the only one in general use for light and power purposes, being copper.

Every conductor offers some resistance to the flow of current, just as every pipe offers resistance to the flow of steam or water. Just how this resistance varies we shall see later on. In order to familiarize ourselves with the most important electrical phenomena let us consider Fig. 1. The current is assumed to leave the battery at the +, or positive, pole and flow along the wires, etc., to the negative, or – pole, and as it passes through the coils of wire wound about the iron bar it produces magnetism in the bar. If the bar is of soft iron the magnetism lasts only while the current is flowing, but a bar of hardened steel will permanently retain its magnetism. The current will also heat the incandescent lamp until it emits light, and the fine wire, *R*, to the melting point, if desired. In passing through the water in the jar, it will decompose it, forming oxygen and hydrogen gas. If, instead of

water, the jar is filled with a proper solution, one of the copper plates in the solution will be gradually eaten away and the other added to. If we now disconnect our wires from the battery and connect 1 at 2, and 2 at 1, the chemical action in the jar will be reversed, the lamp and fine wire, *R*, will heat as before, no difference being noticeable. The iron bar will also be a magnet as before, but the end that before attracted the north seeking end of a compass needle will now repel it and attract the south seeking end of the same

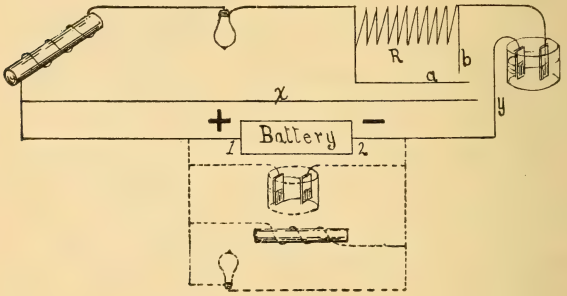


FIGURE 1.

needle. The wire which connects the various devices, and the devices themselves, constitutes an electric circuit, and the current is said to flow in such a circuit along the wire, just as water flows in a pipe. The solid lines form what is known as a series circuit, while the dotted lines form a multiple circuit. In the latter case, each piece of apparatus receives current independent of the others. In the series circuit the same current passes through all. If the small wire *a* is connected to *b*, no current will flow through R; it

will all flow through *a* and *b*. If the wire X be connected to Y, all current will flow through it and none through any other part of the circuit. The current obeys the same law as does water; it takes the path which offers the least resistance to its flow.

Such substances as effectually prevent current from flowing through them are known as insulators. Some of them are

Dry Air,	Mica,
Glass,	Shellac,
Silk,	Oil,
Asbestos,	Paraffine,
Porcelain,	Wool,
Cotton,	Paper,
Rubber,	Gutta Percha,

and because the following substances have a low resistance they are known as conductors of electricity. Their relative conductivity is in the following order, silver being the best:

Silver,
Copper,
Gold,
Platinum
Iron,
Tin,
Lead, etc.

The Ampere. The ampere is the unit of volume or rate of flow, and in speaking of a flow of so many amperes, we mean substantially the same thing, electrically speaking, as though we referred to so many gallons of water, mechanically speaking. The number of amperes flowing over a wire deliver power, much or little, pro-

portional to the electromotive force or pressure under which they flow; just as the number of gallons of water flowing through a pipe toward a water wheel deliver a large or small quantity of power to the wheel, proportional to the pressure under which the water flows. If 100 amperes were flowing at a pressure of 10 volts they would produce the same power as though there were 10 amperes flowing at 100 volts, exactly as 100 gals. of water flowing at a pressure of 10 lbs. to the square inch would produce the same power as 10 gals. flowing at a pressure of 100 lbs. to the square inch. In both cases, however, for convenience, we have not considered the size of either wire or pipe, but with the wire, as with the pipe, as we increase the diameter we decrease the friction or resistance. In speaking of the gallon we, of course, have something material on which we can base the unit gallon. We may take a vessel 1 ft. wide, 1 ft. long and 1 ft. high, and this vessel will hold 1 cu. ft. of water. This cubic foot would contain 7½ gals.; but in the case of the ampere we must adopt another method. We shall take an earthenware tank in which is contained a solution of copper sulphate and add one-tenth of one per cent. sulphuric acid. We shall next take two copper plates and hang them into this solution, keeping them spaced one inch apart, vertically. Having washed these plates in clear water, rounded off the corners and dried them thoroughly, we must next weigh them very carefully before submerging them in the liquid. We may now connect both plates to a source from which we can obtain a current of electricity and allow the current to flow from one plate to another, through the liquid, for a period of time which we must measure by a watch or clock. After current has flowed for several hours we will remove the plates,

wash them in clean water, and then dip in a bath of water containing a very small amount of sulphuric acid to prevent oxidization, dry them and carefully weigh them again. It will be found that the negative plate has increased in weight by what is called electrolytic action. Now weigh the negative plate and ascertain the exact number of grammes of copper deposited on its surface, or, in other words, find how many grammes heavier the plate is now than it was before it went into the bath. With these data in our possession we will multiply the time in seconds that current was passing through the plates by .000329 and divide the number of grammes deposited on the plate by the result. The quotient will be the number of amperes that passed from plate to plate. This I give simply to show you the manner in which the ampere can be ascertained. It is that current which will deposit .000329 gramme per second on one of the plates of a voltameter, as above described. It is also the current produced by one volt acting through a resistance of one ohm.

In other words, the ampere is that current which would be forced over a wire having a resistance of one ohm by a pressure of one volt.

The ampere-hour is the unit of electrical quantity in general use. It is the quantity of electricity conveyed by one ampere flowing for one hour, or one-half ampere flowing for two hours; or again, one-fourth ampere flowing for four hours. In each case the sum total would be one ampere-hour. It must, however, be noted that an ampere-hour with the pressure at 110 volts would deliver just one-half as much power as an ampere-hour at 220 volts.

An ordinary 16-candle-power 110 volt incandescent lamp requires a current of about one-half an ampere,

while a lamp of the same candle-power at 220 volts requires but one-fourth of an ampere, and a 52 volt lamp about one ampere.

A milli-ampere is the one-thousandth ($\frac{1}{1000}$) part of an ampere.

The Coulomb. The Coulomb is the unit of quantity. It is the quantity of current delivered by one ampere flowing for one second.

The Volt. By electromotive force, volts, or potential, we mean electrically about the same as we do when speaking of pounds pressure as indicated on a steam gauge. If we connect a volt-meter between a positive and a negative wire we find that it indicates a certain number of volts; the volt-meter then indicates electrical pressure just as a steam gauge indicates steam pressure. The difference in potential or pressure between two wires we will assume to be 100 volts, and the difference of potential between the inside of a pipe and the atmosphere also at 100 lbs. to the square inch. The steam gauge is closed at one end of the tube which operates it, and hence, the pressure from the interior of the pipe does not flow into the atmosphere; in other words, the resistance offered to the pressure prevents the water from escaping into the atmosphere. In the case of the volt-meter the resistance of the wires used in its construction prevents any great quantity of electricity from flowing out of the positive wire and into the negative through the volt-meter coil. If the gauge were accidentally broken off the pipe, the resistance to the pressure on the inside of the pipe would be greatly lowered and allow the water to flow into the atmosphere. If a piece of ordinary wire were connected to the positive and negative wires, where we have just connected our volt-meter, it would form a path of such

low resistance and allow all the current to flow through it, so there would be no pressure indicated in the volt-meter. This would be called a "short circuit." With a volt-meter there is always a small amount of current flowing from a positive to a negative wire through the coil in the meter. This current is neccesary to produce the reading on the meter, but we need not consider this current at present, the quantity being very small.

One volt (unit of pressure) will force one ampere (unit of current) over one ohm (unit of resistance).

Potential is a term quite frequently used to express the same idea as voltage or electromotive force, but its meaning is somewhat different. Suppose that a steam engine is working with 100 lbs. of pressure at the throttle valve, and exhausting into a heating system or system of piping that offers a back pressure of 5 lbs. to the square inch; in other words, the resistance to the flow of steam out of the exhaust pipes of this engine is such that the remaining pressure, when the engine has exhausted, is 5 lbs. Now it will readily be seen that the total pressure utilized to do the work would be 100 lbs. less 5 lbs., or 95 lbs., and therefore the potential would be 95 lbs. Now, if we are using electricity at 100 volts pressure, and lose 5 volts in overcoming resistance, we have a potential of 95 volts left. Whenever work is done by a steam engine a certain amount of pressure is lost by condensation, doing work and by overcoming friction. This loss may be considered the same as a loss of potential, for in the use of electricity any loss in pressure of volts that may occur from doing work or overcoming resistance is called a loss of potential.

In open arc lamps the loss of potential across the terminals or binding posts is about 50 volts; that is, 50

volts have been absorbed or used in producing light. You can now readily understand that electromotive force means force, pressure, energy, and that by potential we mean the capacity to do work or the effective pressure to do work. While we are speaking of electromotive force we may consider some of the advantages of high and low electromotive forces. High electromotive force, like steam at high pressure, is far more economical in transmission or utilization because the quantity may be that much smaller.

When transmitted to great distances, high electromotive forces, like high water or steam pressures, are far more desirable on account of the reduction in friction losses; but this is partially offset by the necessity of using, in water transmission, a much stronger pipe for the high pressure than would be necessary for the low pressure, and in the transmission of current at a high electromotive force or pressure it becomes necessary to use wires with far better insulating material than would be required for the transmission of electricity at low pressure. Increasing the pressure or electromotive force always means more danger, even if you know the pipes are extra strong or the insulation of the wire is of unusually high resistance; for if anything should happen the consequences would be far more serious with high than with low pressures. But notwithstanding all this, engineers are continually increasing the pressures of electrical machinery.

Static electricity is a term applied to electricity produced by friction, and a static discharge of electricity usually consists of an infinitely small quantity but a very high electromotive force or pressure. Discharges of lightning are extremely high in voltage, but the quantity of current that flows is very small.

The Ohm. The ohm is the unit of resistance. Resistance, electrically speaking, is much the same thing as friction in mechanics. If a wire or pipe of a certain length is delivering 10 gals. or 10 amperes at a pressure of 100 lbs. or 100 volts, and we propose to double the flow without increasing the pressure, it will be necessary for us to increase the diameter of the pipe and wire in order to lower the resistance of the wire and the friction of the pipe to one-half of what it was before. If we desire the best results from the pipe, we lower its friction by reaming out all burrs and avoiding all unnecessary bends and turns; likewise if we desire the best results from the wire we will have the copper of which it is constructed as nearly pure as possible, and we will install the wire where its temperature will not be unnecessarily high, avoiding boiler rooms and other hot places. Resistance of the wire increases slightly with an increase in temperature.

For every additional degree centigrade the resistance of copper wire increases about 0.4 per cent., or for every additional degree Fahrenheit about 0.222 per cent. Thus a piece of copper wire having a resistance of 10 ohms at 32° F. would have a resistance of 11.10 ohms at 82° F. An annealed wire is also of lower resistance than a hard drawn wire of the same size. A good idea of the value of an ohm may be had from the following table, which gives the length of different wires required to make one ohm resistance.

FEET PER OHM OF WIRE (B. & S.).

94	feet of	No. 20	605	feet of	No. 12
150	"	18	961	"	10
239	"	16	1529	"	8
380	"	14	2432	"	6
			3867	feet of	No. 4

We have not as yet established a unit of mechanical friction, therefore when we speak of mechanical friction we refer to it as requiring a certain quantity of power to overcome it. When, however, resistance to the flow of electricity is spoken of it is referred to as so many ohms. It can be measured in several ways, the most reliable and convenient being by an instrument called the Wheatstone Bridge. It can also be calculated if the length and diameter of the wire or conductor is known, as will be shown later on.

The basis of all electrical calculation is Ohm's law. This law reads:

"The strength of a continuous current in a circuit is directly proportional to the electromotive force acting on that circuit, and inversely proportional to the resistance of the circuit." In other words, the current is equal to the volts divided by the ohms. Expressed in symbols, $C = E/R$; C being current, E voltage, and R resistance. If an incandescent lamp having a resistance of 200 ohms be placed in a socket where the pressure is 115 volts, the resulting current through such a lamp would be 115 divided by 200, or .575 of an ampere.

From the formula $C = E/R$, two others are deduced. The volts divided by the amperes equal the ohms, $E/C = R$.

The amperes multiplied by the ohms equal the volts, $C \times R = E$.

The Watt. The watt is the unit of power. It is an ampere multiplied by a volt; just as the unit of mechanical power, called the foot pound, is the result of the pound multiplied by the space in feet through which it moves. If a current of say 100 amperes, flows over a wire at a pressure of 10 volts, the power delivered will equal

100 amperes × 10 volts = 1,000 watts. If a current of 10 amperes flows over a wire at a pressure of 100 volts, the power would be exactly the same, 10 amperes × 100 volts, or 1,000 watts. But, of course, in the first case it would require a wire ten times as large to deliver the 1,000 watts as would be necessary in the latter case. If a weight of 10 pounds were being elevated through space at the rate of 100 ft. per minute the power equivalent would be 10 lbs. × 100 ft., or 1,000 ft. lbs. If an arc lamp consumes 10 amperes at a pressure of 70 volts, its power consumption is 10 × 70, or 700 watts. One watt is the power developed when 44.25 ft. lbs. of work are done per minute. Seven hundred forty-six watts equal one horse power. The watt-hour is the unit of electric work, and is a term employed to indicate the expenditure of one watt for one hour. The kilo watt-hour is the term employed to indicate the expenditure of an electric power of 1,000 watts for one hour.

The work done per second when a power of one watt is being developed is called the joule, and a joule is equal to .7375 ft. lbs.

Electromotive force times current equals watts. The square of the current multiplied by the resistance equals watts; and the voltage multiplied by itself and divided by the resistance equals watts. Expressed in symbols, these explanations would look like this:

$$W = E \times C. \qquad W = C^2 \times R. \qquad W = E^2 \div R.$$

First. If we have an electromotive force or voltage of 10 volts and a current of 20 amperes, we have 10 × 20 = 200 watts.

Second. If we have a current of 10 amperes and a resistance of 30 ohms, we would have 10 × 10 × 30 = 3,000 watts.

Third. If we have an electromotive force or voltage of 10 volts and a resistance of 20 ohms, we would have 10×10, or $100 \div 20$, or 5 watts.

In the above formulas E stands for voltage, C for current, R for resistance and W for watts.

Divided Circuits. Currents of electricity, although they have no such material existence as water or steam, still obey the same general law; that is, they flow and act along the lines of least resistance. If a pipe extending to the top of a ten story building had a very large opening at the first floor, it would be impossible to force water to the top floor. All the water would run out at the first floor. If the opening at the first floor were small only a part of the water would escape through it, some would reach the top of the building. The flow of water in each case is inversely proportional to the resistance offered to it by the different openings.

The same thing is true of currents of electricity. Where several paths are open to a current of electricity the flow through them will be in proportion to their conductivities, which is the inverse ratio of their resistances. As an illustration, the current flow through all of the lamps, Fig. 2, is the same, because

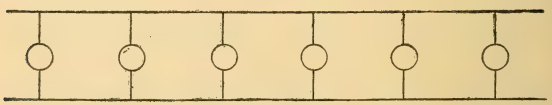


FIGURE 2.

each lamp offers the same resistance. But if we arrange a number of lamps as in Fig. 3, the lamps in series will offer twice as much resistance as the single

FIGURE 3.

lamps, and will receive but half the current of the single lamp. In Fig. 4 we have still another arrangement. The lamp A limits the current which can flow through B and C, and that current which does flow

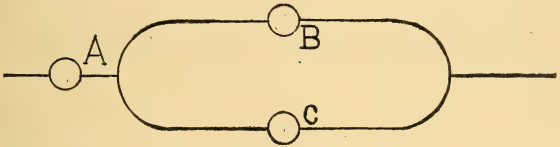


FIGURE 4.

divides between B and C in proportion to their conductivities. If B has a resistance of 110 ohms and C 220 ohms, then B will carry two parts of the current and C only one. The combined resistance of all lamps, Fig. 2, equals the resistance of one lamp divided by the number of lamps. The combined resistance, Fig. 3, equals the sum of the resistances of the two lamps at A multiplied by the resistance of B and divided by the sum of all the resistances. If the resistance of each of the lamps were 110 ohms, the problem would work out thus: $\frac{110+110\times 110}{110+110+110} = 73\frac{1}{3}$.

In Fig. 4 the total resistance is $\frac{110\times 220}{110+220} + 110 = 183\frac{1}{3}$.

One practical illustration of the above law may be found in the method of switching series arc lamps,

Fig. 5. As long as the switch S is open the arc lamp burns, but as soon as the switch is closed the lamp is

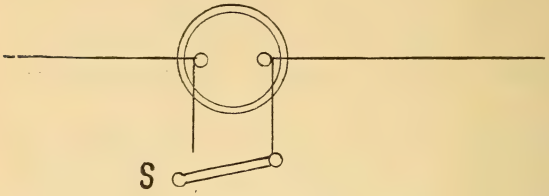


FIGURE 5.

extinguished because the resistance of the short wire and the switch S is so much less than that of the arc lamp that practically all the current flows through S.

CHAPTER II

WIRING SYSTEMS — CALCULATION OF WIRES — WIRING TABLES.

Wiring Systems. The system of wiring which is most generally used for incandescent lighting and ordinary power purposes is called the two wire parallel system. In this system of wiring the two wires run side by side, one of them being the positive and one the negative. The lamps, motors and other devices are then connected from one wire to the other. A constant pressure of electricity is maintained between the two wires, and the number and size of lamps, or other apparatus, connected to these two wires, determine how many amperes are required. Each lamp or motor is independent of the others and may be turned on or off without disturbing the others.

A diagram of such a system is shown in Fig. 6.

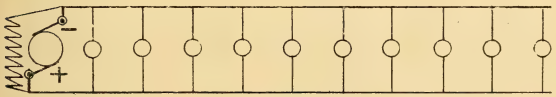


FIGURE 6.

In this system the quantity of current varies in proportion to the number of devices connected to it. Suppose that we are maintaining a pressure or potential or electromotive force of 110 volts on such a system, and that we have connected to the system ten 16 candle power incandescent lamps, consuming one-half

ampere each. The total quantity of current to supply these lamps would be 5 amperes. If we should now switch on ten more lamps the quantity of current would be 10 amperes, and the pressure would remain 110 volts. This system is also known as the "constant potential system," or multiple arc system, and among the numerous devices used in connection with it are the constant potential arc lamp, the shunt motor, the compound wound motor, the series motor, incandescent lamps, etc. Electric street railways are also operated on this system. The electricity supplied through this system of wiring may be either direct or alternating current.

The series arc system, Fig. 7, is a loop; the greatest electrical pressure being at the terminal or terminal ends

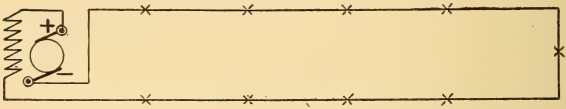


FIGURE 7.

of the loop. The current in such a system of wiring is constant, and the pressure varies as the lamps or other apparatus are inserted in or cut out of the circuit. This system is also called the constant current system. The same current passes through all of the lamps, and the different lamps are also independent of each other.

At the present time the series system is used mostly for operating high tension series arc lamps. The use of motors with it has been almost entirely abandoned.

The series multiple system, Fig. 8, is simply a number of multiple systems placed in series. This method of wiring was at one time employed to run incandes-

cent lights from a high tension series arc light circuit, but on account of the danger connected with the use

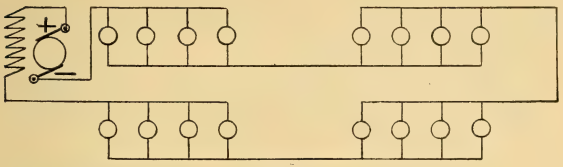


FIGURE 8.

of incandescent lamps, operated from a high tension arc lamp circuit, the system has been abandoned. It is not approved by insurance companies, and consequently is not often used.

The multiple series system consists of a number of small series circuits, connected in multiple, as shown in Fig. 9. This system of wiring is used on constant

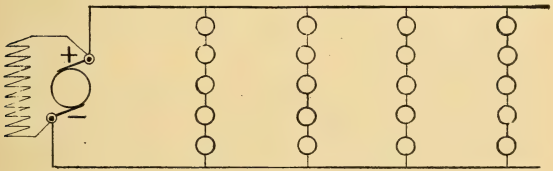


FIGURE 9.

potential systems, where the voltage is much greater than is required by the apparatus to be used, as, for instance, connecting eleven miniature lamps, whose individual pressure required is 10 volts, into a series, and then connecting the extreme ends of such a series to a multiple circuit whose pressure is 110 volts. In electric street cars, where the pressure between the

trolley wire and the running rail is 500 volts, it will be noticed that the lighting circuits in the car consist of five 100 volt lamps in series, and one end of this series is connected to the trolley line, the other end being grounded on the trucks.

The three wire system, Fig. 10, is a system of multiple series. In this system, as its name implies, three wires are used, connected up to the machines in

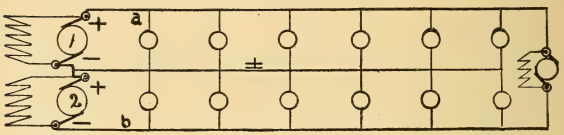


FIGURE 10.

the manner shown in the diagram. Both machines are in series when all lights are turned on, but should all lights on one side of the neutral or center wire be turned off the machine on the other side alone would run the other lights.

One of these wires is positive, the other is negative, and the remaining one or center wire is neutral. In ordinary practice from positive to negative wire, a potential of 220 volts is maintained, while from the neutral wire to either of the outside wires a potential of 110 volts exists. The advantages of such a system are many, principally among them is the use of double the voltage of the two wire system; this reduces the current one-half and allows the use of smaller wires. This system only requires three wires for the same amount of current that would require four in the other system. Motors are supplied at 220 volts, while lights operate at 110. Incandescent lighting circuits

can be maintained from either outside wire to the neutral wire. The saving in copper by dispensing with the fourth wire is not the only advantage in the saving of conductors. The neutral wire may be much smaller than the outside wires because it will seldom be called upon to carry much current.

Inside of buildings, however, where overheating of a wire is always dangerous, the neutral wire should be of the same size as the others. By tracing out the circuits in Fig. 10, it will readily be seen that, so long as all lamps are burning, the current passes out of dynamo 1 into the positive wire and from there through the lamps (always two in series) to the negative or – wire, returning over it to the – pole of dynamo 2. So long as an equal number of lamps is burning on each side of the neutral, no current passes over the neutral wire in either direction. But if the positive or + wire should be broken, say at *a*, dynamo 1 will no longer send current and the lamps between the positive and neutral wire will be out.

Dynamo 2 will now supply the lamps between the neutral and the negative wire and for the time being the neutral wire will become positive. Should the negative wire break at *b*, the lamps connected to it would be out and dynamo 1 would supply the lights on its side, the neutral wire becoming negative. When motors of one or more H. P. are used on this system, it is usual to connect them to the outside wires using 220 volts. It is important also to arrange the wiring so that an equal number of lights are installed on each side of the neutral. When the lights and motors are so arranged, the system is said to be "balanced." It is also very important to arrange so that the neutral wire cannot readily be broken. Should the neutral

wire be opened while, for instance, fifty lamps were burning on one side and say ten or twenty on the other, the ten or twenty would be broken by the excess voltage. Grounded wires ordinarily cause more trouble than anything else on electric light or power circuits, but with the three wire system, the neutral wire is often grounded. Grounds on this wire are less objectionable than on other wires, because it carries very little current, and that current is constantly varying in direction, so that no great amount of electrolysis can occur at any one place. For full descriptions and drawings of methods of wiring, see *Wiring Diagrams and Descriptions* by Horstmann and Tousley, published by Frederick J. Drake & Co., Chicago.

Feeders (see Fig. 11), as the name implies, is a term used to designate wires which convey the current to

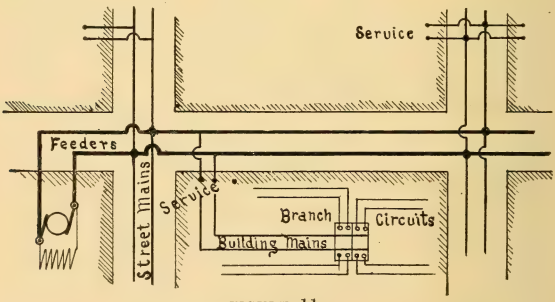


FIGURE 11.

any number of other wires, and the feeders become a part of the multiple series, multiple and three wire systems.

Distributing mains are the wires from which the wires entering buildings receive their supply.

Service wires are the wires that enter the buildings.

The center of distribution is a term used for that part of the wiring system from which a number of branch circuits are fed by feeder wires. In most buildings the tap lines are all brought to one point, and terminate in cut-out boxes. These cut-out boxes are supplied by the main. Each floor of the building may have a cut-out box, or each floor of the building may have several cut-out boxes of the above description.

Calculation of Wires. If we desire to transmit or deliver a certain quantity of liquid through a pipe, we estimate the size of the pipe and the comparison of sizes in the pipes by squaring the diameter, in inches, and multiplying the result by the standard fraction .7854. By way of explanation we will dwell upon the above method for a short time. In Fig. 12 we have a surface which measures one inch on all four sides, and which has an area of one square inch.

FIGURE 12.

Now in a circle which is contained in this figure, and which touches all four sides of the square, we would only have .7854 of a square inch. If the diameter of this circle is 2 in., instead of 1, you can readily see by Fig. 13 that its area is four times as great or $2 \times 2 = 4$. We then multiply by the standard number .7854 in order to find the area contained in the two-inch circle; and if the diameter were 3 in., then $3 \times 3 = 9$, and $9 \times .7854$ would be the area in square inches contained in the three-inch circle.

Again, if we had a square one inch in area, like Fig. 14, and we took one leg of a carpenter's compass and placed it on one corner of this square, striking a

quarter-circle from one adjacent corner to the other adjacent corner, the area inscribed by the compass would again be .7854 of a square inch.

The above will explain to the reader the relation

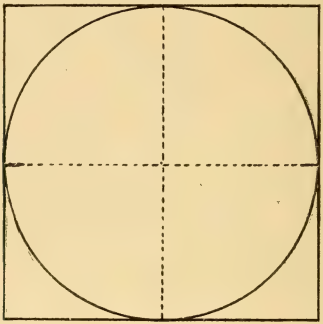


FIGURE 13.

between the circular and square mil. The circular mil is a circle one mil ($\frac{1}{1000}$ of an inch) in diameter. The square mil is a square one mil long on each side. In the calculation of wires for electrical purposes, the circular mil is generally used, because we need only multiply the diameter of a wire by itself to obtain its area in circular mils. If we used square mils we should have to multiply by .7854.

FIGURE 14.

The resistance of a conductor (wire) increases directly as its length, and decreases directly as its diameter is increased. A wire having a diameter of one mil and being one foot long has a resistance at ordinary temperature of 10.7 ohms. If this wire were two feet long, it would have

a resistance of 21.4 ohms, but if it were two mils in diameter and one foot long, it would have a resistance one-fourth of 10.7, or about 2.67.

Every transmission of electrical energy is accompanied by a certain loss. We can never entirely prevent this loss any more than we can entirely avoid friction. But we can reduce our loss to a very small quantity simply by selecting a very large wire to carry the current. This would be the proper thing to do if it were not for the cost of copper, which would make such an installation very expensive. As it is, wires are usually figured at a loss of from 2 to 5 per cent.

The greater the loss of energy we allow in the wires the smaller will be the cost of wire, since we can use smaller wires with the greater loss.

In long distance transmission and where the quality of light is not very important, a loss of 10 or 20 per cent. is sometimes allowed, but in stores, residences, etc., the loss should not exceed 2 or 3 per cent., otherwise the candle power of the lamps will vary too much.

Where the cost of fuel is high the saving in first cost of copper is soon offset by the continuous extra cost of fuel to make up for the losses in the wires.

To determine the size of wire necessary to carry a certain current at a given number of volts loss, we may proceed in the following manner: Multiply the number of feet of wire in the circuit by the constant 10.7, and it will give the circular mils necessary for one ohm of resistance. Multiply this by the amperes, and this will give the circular mils for a loss of one volt. Divide this last result by the volts to be lost, and the answer will be the number of circular mils diameter that a copper wire must have to carry the current with such a loss. After obtaining the number of circular mils

required, refer to the table of circular mils, and select the wire having such a number of circular mils.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Volts lost}} = \text{circular mils.}$$

By simply transposing the above terms we obtain another formula, which can be used to determine the volts lost in a given length of wire of a certain size, carrying a certain number of amperes.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Circular mils}} = \text{Volts lost.}$$

And again, by another change in the terms we obtain a formula which shows the number of amperes that a wire of given size and length will carry at a given number of volts lost:

$$\frac{\text{Circular mils} \times \text{volts lost}}{\text{Feet of wire} \times 10.7} = \text{Amperes.}$$

In computing the necessary size of a service or main wire, to supply current for either lamps or motors, it is necessary to know the exact number of feet from the source of supply to the center of distribution. When the distance of center of distribution is given it is well to ascertain whether it is the true center or not. It may be only the distance from a cut-out box that has been given, when it should have been the distance from the point at which the service enters the building or, perhaps, from the point at which the service is connected to the street mains. For when the size is determined it is for a certain loss which is distributed over the entire length of the wire to be installed. The transmission of additional current on the mains in the building increases the drop in volts in the main, and likewise

in the service. Most buildings are wired for a certain per cent loss in voltage, estimated from the point where the service enters the building. All additions should be estimated from that point.

In using the formula for finding the proper size wire to carry current, the first thing to be determined is the length of the wire; remember that the two wires are in parallel, and therefore the total length of the wire is twice the total distance from the commencement to the end of the circuit. If the proposed load on this circuit is given in lamps, you may reduce it to amperes, and if the proposed load is given in horsepower, you may reduce it to amperes. The voltage on the circuit is known in either case. You take the loss of the voltage and divide the product of amperes, multiplied by the length, as found, and 10.7 by it; this answer will be the size in circular mils of a wire necessary to carry the amperes.

Example: What is the size of wire required for a 50 volt system, having 100 lamps at a distance of 100 ft., with a 4 per cent loss?

Answer: The load of 100 lamps on a 50 volt system is 100 amperes, and a 4 per cent loss of 50 volts is 2 volts. Multiply the total length of the wire, which is twice the distance, or 200 ft., by the 100 amperes of current; this gives us 20,000. Then multiply this by the constant, which is 10.7; this gives us 214,000. Divide this by 2, which is the loss in volts, and you have 107,000 circular mils diameter of wire required

When determining the size of wire to be used it is always necessary to consult the table of carrying capacities, and this will very often indicate a wire much larger than that determined by the wiring formula, especially if a somewhat high loss is figured on.

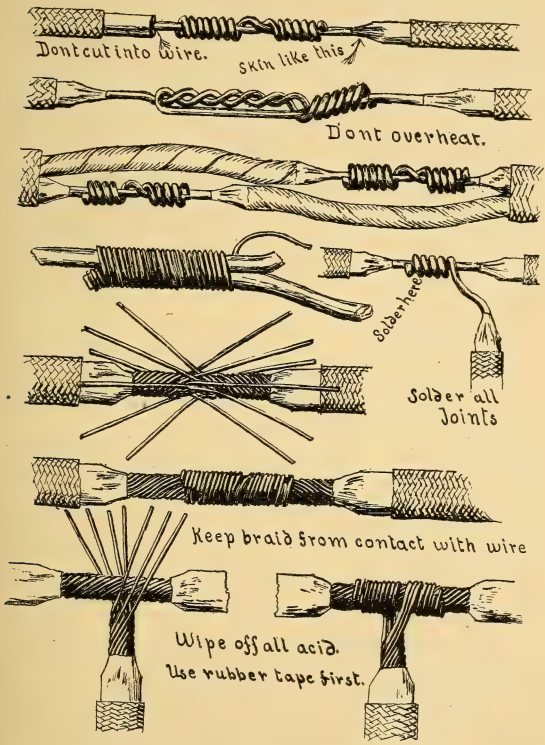
When estimating the distance it is not always correct to take the total distance.

To illustrate: Suppose one lamp is 100 ft. from the point at which the distance is determined, and the farthest lamp is 400 ft., the remaining lamps being distributed evenly between these two points; we would average the distances between the first and last lamp, which would be 200 ft. It is necessary to use judgment in estimating the mean or average distance, as the lamps or motors are bunched differently in each case

In a series system the loss in voltage makes considerable difference to the power, but does not affect the quality of the light as much as in a multiple arc or parallel system. In a parallel system the lamps require a uniform pressure, and this can only be had by keeping the loss low. In a series system the lamps depend upon the constant current and the voltage varies with the resistance, in order to keep the current constant. This is accomplished by a regulator on the dynamo, which is designed to compensate for the changes of resistance in the circuit and to increase or decrease the pressure as required.

In estimating the size of wire for a series system you consider the total length of the loop. There is no average distance as the total current travels over the entire circuit. We will assume that you have an arc light circuit of a No. 6 Brown & Sharp gauge wire and want to find what loss there is in this circuit. You have the area of a No. 6 wire, which is 26,250 circular mils, and the length of the circuit, and from this we will figure the loss in this manner: Assuming the circuit to be 10,000 ft. long, and the current 10 amperes, we will multiply 10,000 ft. by 10 amperes,

and this by 1.07, which gives us 1,070,000, and divide this by 26,250. The answer is 40 volts, lost in the circuit.



Such a circuit would operate at perhaps 2,000 or 3,000 volts, and a loss of 40 volts would not be exces-

sive. It would be wasting a little less energy than is required to burn one large arc lamp.

The *multiple series system* is a number of small wires connected in multiple, and is the same as the multiple arc or parallel system. The wire is figured in the same way as for the multiple arc system.

The *series multiple system* is a number of small parallel systems, and these are connected in series by the main wire. The wire is figured the same as for the series system.

The *Edison three-wire system* is a double multiple, and the two outside wires are the ones considered when carrying capacity is figured. When this system is under full load or balanced, the neutral wire does not carry any current, but the blowing of a fuse in one of the outside wires may force the neutral wire to carry as much current as the outside wire and it should, therefore, be of the same size. The amount of copper needed with this system is only three-eighths of that required for a two-wire system.

Wiring Tables. On the following pages are presented wiring tables for 110,220 and 500 volt work. These tables are used in the following manner: Suppose we wish to transmit 60 amperes a distance of 1,800 ft. at 110 volts and at a loss of 5 per cent. We take the column headed by 60 in the top row and follow it downward until we come to 1,800, or the number nearest to it. From this number we now follow horizontally to the left, and under the column headed by 5 we find the proper size of wire, which is 500,000 c. m. The same current, at a loss of 10, would require only a 0000 wire, as indicated under the column at the left, headed by 10.

Before making selection of wire, always consult the

table of carrying capacities, page 38. This table is taken from the rules of the National Board of Fire Underwriters, and is in general use.

The first three of the following tables are wiring tables for the three standard voltages, 110, 220, 500 From these tables can be found the sizes of wire required to carry various amounts of current (in amperes) different distances (in feet) at several percentages of loss, or the distance the different sizes of wire will carry various amounts of current at several percentages of loss can be found.

These tables are figured on safe carrying capacity for the different sizes of wire. The distances in feet are to the center of distribution.

110-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	125	150	200	250	300	350
.....	.....	.....	.....	.....	500000	127315	67657	42438	25463	16975	12731	10185	8487	6365	5092	4243	3182	2546	2037	1697	1273	1018	849	727
.....	.....	.....	.....	500000	400000	101850	50925	33950	20370	13580	10185	8148	6790	5092	4074	3395	2546	2037	1629	1358	1018	815	679	....
.....	.....	.....	500000	400000	300000	76380	38190	25460	15276	10184	7638	6111	5092	3819	3055	2546	1910	1527	1222	1018	763	611	.....	.....
.....	.....	500000	400000	300000	0000	53380	26940	17960	10776	7184	5388	4311	3592	2694	2155	1796	1347	1077	862	718	538	.....	.....	.....
.....	.....	400000	300000	0000	000	40410	20205	13470	8082	5488	4041	3233	2744	2020	1616	1372	1010	808	647	538	.....	.....	.....	.....
.....	500000	300000	0000	000	00	33885	16942	11295	6777	4517	3388	2711	2258	1694	1355	1129	822	677	542	452	.....	.....	.....	.....
.....	400000	0000	000	00	0	26880	13440	8960	5377	3584	2688	2151	1792	1344	1075	896	672	537	430	.....	.....	.....	.....	.....
500000	300000	000	00	0	1	21310	10655	7103	4262	2841	2131	1705	1420	1065	852	710	532	426	341	.....	.....	.....	.....	.....
400000	0000	00	0	1	2	16900	8450	5633	3380	2253	1690	1352	1126	845	676	563	422	338	.....	.....	.....	.....	.....	.....
300000	000	0	1	2	3	13400	6700	4466	2680	1786	1340	1072	893	670	536	447	335	.....	.....	.....	.....	.....	.....	.....
0000	00	1	2	3	4	10605	5302	3535	2121	1413	1060	848	706	530	424	353	.....	.....	.....	.....	.....	.....	.....	.....
000	0	2	3	4	5	8430	4215	2810	1686	1124	843	675	562	422	337	281	.....	.....	.....	.....	.....	.....	.....	.....
00	1	3	4	5	6	6685	3342	2228	1337	890	668	535	445	334	267	.....	.....	.....	.....	.....	.....	.....	.....	.....
0	2	4	5	6	7	5300	2650	1766	1060	706	530	424	353	265	212	.....	.....	.....	.....	.....	.....	.....	.....	.....
1	3	5	6	7	8	4220	2110	1406	844	562	422	338	281	211	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	4	6	7	8	9	3330	1665	1110	666	444	333	266	222	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	5	7	8	9	10	2640	1320	880	528	352	264	211	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	6	8	9	10	11	2095	1047	698	419	278	209	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	7	9	10	11	12	1660	830	553	333	221	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	8	10	11	12	13	1320	660	440	264	176	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	9	11	12	13	14	1045	522	348	209	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	10	12	13	14	15	830	415	276	166	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	11	13	14	15	16	655	327	218	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	12	14	15	16	.....	525	263	175	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	13	15	16	.....	.....	412	206	137	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	14	16	.....	.....	.....	330	165	111	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	15	.....	.....	.....	.....	263	131	87	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	16	.....	.....	.....	.....	206	103	68	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	.....	.....	.....	.....	.....	165	82	55	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16	.....	.....	.....	.....	.....	131	65	43	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

One 16-Candlepower 55 Watt Incandescent Lamp=½ ampere. One Horsepower= 6.78 amperes. One 2000-Candlepower Constant Potential Arc Lamp=5 amperes.

220-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the number of Amperes: Those Below the Distance in Feet.																	
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	160	200	250	300	350
.....	.....	.....	.....	.....	500000	254630	127315	84877	50926	33950	25463	20370	16975	12731	10185	8487	6366	5092	4243	3183	2546	2037	1697	1455
.....	.....	.....	.....	500000	400000	203700	101850	67900	40740	27160	20370	16295	13580	10185	8147	6790	5092	4073	3395	2546	2036	1629	1357	.....
.....	.....	.....	500000	400000	300000	152775	76387	50924	30550	20370	15275	12222	10183	7637	6111	5091	3819	3055	2546	1910	1528	1222	.....	.....
.....	.....	500000	400000	300000	0000	107780	53890	35926	21556	14370	10778	8622	7185	5389	4311	3592	2695	2155	1796	1348	1077	.....	.....	.....
.....	.....	400000	300000	0000	000	85450	42725	28483	17090	11393	8545	6836	5696	4272	3418	2848	2136	1709	1424	1068	.....	.....	.....	.....
.....	500000	300000	0000	000	00	67745	33872	22581	13549	9032	6774	5420	4516	3387	2710	2258	1679	1355	1129	839	.....	.....	.....	.....
.....	400000	0000	000	00	0	53770	26885	17923	10754	7170	5377	4302	3585	2688	2151	1792	1344	1075	896	.....	.....	.....	.....	.....
500000	300000	000	00	0	1	42620	21310	14206	8524	5682	4262	3410	2841	2131	1705	1420	1065	852	710	.....	.....	.....	.....	.....
400000	0000	00	0	1	2	34055	17027	11351	6811	4540	3405	2724	2270	1702	1362	1135	851	681	.....	.....	.....	.....	.....	.....
300000	000	0	1	2	3	26570	13285	8856	5314	3542	2657	2125	1771	1328	1062	885	664	.....	.....	.....	.....	.....	.....	.....
0000	00	1	2	3	4	21255	10627	7085	4251	2834	2125	1700	1417	1062	850	708	.....	.....	.....	.....	.....	.....	.....	.....
000	0	2	3	4	5	16855	8427	5618	3371	2247	1685	1348	1123	842	614	562	.....	.....	.....	.....	.....	.....	.....	.....
00	1	3	4	5	6	13365	6682	4455	2673	1782	1336	1050	891	668	525	.....	.....	.....	.....	.....	.....	.....	.....	.....
0	2	4	5	6	7	10560	5280	3520	2112	1413	1060	848	706	530	424	.....	.....	.....	.....	.....	.....	.....	.....	.....
1	3	5	6	7	8	8405	4202	2801	1681	1120	840	672	560	420	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	4	6	7	8	9	6665	3332	2221	1333	888	666	533	444	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	5	7	8	9	10	5275	2637	1758	1055	703	527	422	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	6	8	9	10	11	4190	2095	1396	838	558	419	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	7	9	10	11	12	3325	1662	1108	665	443	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	8	10	11	12	13	2635	1317	878	527	351	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	9	11	12	13	14	2090	1045	696	418	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	10	12	13	14	15	1655	827	551	331	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	11	13	14	15	16	1315	657	438	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	12	14	15	16	.....	1050	525	350	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	13	15	16	.....	.....	828	414	276	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	14	16	.....	.....	.....	657	328	219	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	15	.....	.....	.....	.....	526	263	175	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	16	.....	.....	.....	.....	414	207	138	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	.....	.....	.....	.....	.....	329	164	109	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16	.....	.....	.....	.....	.....	265	132	88	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

One 16-Candlepower 55 Watt Incandescent Lamp=¼ ampere. One Horsepower=3.39 amperes. One 2000-Candlepower Constant Potential Arc Lamp=2½ amperes.

500-VOLT WIRING TABLE.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.

The Top Figures in Each Column are the Number of Amperes: Those Below the Distance in Feet.

2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	150	170	200
.....	.....	.....	.....	.....	500000	578700	289350	192900	115740	77160	57870	46296	38580	28935	23148	19290	14467	11574	9645	7716	6800	5787
.....	.....	.....	.....	500000	400000	460645	230322	153550	92129	61420	46064	36852	30710	23032	18426	15355	11516	9213	7677	6142	5420	4606
.....	.....	.....	500000	400000	300000	347220	173610	115740	69444	45296	34722	27777	22648	17361	13888	11324	8680	6944	5662	4629	4085	3472
.....	.....	500000	400000	300000	0000	244950	122475	81650	48990	32660	24495	19595	16330	12247	9797	8165	6123	4898	4082	3266	2882	2449
.....	.....	400000	300000	0000	000	194215	97107	64738	38843	25895	19421	15537	12947	9710	7768	6473	4855	3884	3236	2589	2285	.....
.....	500000	300000	0000	000	00	154025	77012	51341	30805	20536	15402	12322	10268	7701	6161	5134	3850	3080	2567	2054	.....	.....
.....	400000	0000	000	00	0	122210	61105	40736	24442	16293	12221	9775	8146	6110	4887	4073	3055	2443	2036	.....	.....	.....
500000	300000	000	00	0	1	96905	48202	32135	19281	12854	9640	7712	6427	4820	3856	3213	2410	1928	1606	.....	.....	.....
4000 0	0000	00	0	1	2	76565	38282	25521	15313	10208	7656	6125	5104	3828	3062	2552	1914	1531	.....	.....	.....	.....
300000	000	0	1	2	3	60915	30457	20305	12183	8122	6091	4873	4061	3045	2436	2 30	1522	.....	.....	.....	.....	.....
00 0	00	1	2	3	4	48310	24155	16103	9662	6441	4831	3864	3220	2415	1932	1610	.....	.....	.....	.....	.....	.....
000	0	2	3	4	5	38282	19140	12760	7656	5104	3828	3062	2552	1914	1531	1276	.....	.....	.....	.....	.....	.....
00	1	3	4	5	6	30457	15223	10152	6091	4061	3045	2436	2030	1522	1218	.....	.....	.....	.....	.....	.....	.....
0	2	4	5	6	7	24155	12077	8051	4831	3220	2415	1932	1610	1207	966	.....	.....	.....	.....	.....	.....	.....
1	3	5	6	7	8	19140	9570	6380	3828	2552	1914	1531	1276	957	.....	.....	.....	.....	.....	.....	.....	.....
2	4	6	7	8	9	15229	7614	5076	3045	2030	1522	1218	1015	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	5	7	8	9	10	12077	6039	4026	2415	1610	1207	978	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	6	8	9	10	11	9570	4785	3190	1914	1276	957	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	7	9	10	11	12	7639	3819	2546	1527	1018	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
6	8	10	11	12	13	6039	3019	2013	1207	805	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	9	11	12	13	14	4785	2392	1595	957	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
8	10	12	13	14	15	3819	1910	1273	763	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	11	13	14	15	16	3019	1510	1005	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
10	12	14	15	16	.....	2392	1195	797	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
11	13	15	16	.....	.....	1910	950	636	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
12	14	16	.....	.....	.....	1510	755	503	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	15	.....	.....	.....	.....	1195	597	398	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	16	.....	.....	.....	.....	950	475	316	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
15	.....	.....	.....	.....	.....	755	377	252	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
16	.....	.....	.....	.....	.....	597	298	199	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

One Horsepower =1.49 amperes. When lights are used the lamps are put in series.

TABLE OF SIZES, MEASUREMENTS, WEIGHTS, ETC., OF COPPER WIRE.

Size B. & S. Gauge	Diam. Mils	Area		Weather-Proof Wire						Bare Wire			Resistance at 75° F.			
				Double Braided			Triple Braided									
		Circular Mils	Square Mils	Pounds per 1000 feet	Pounds per mile	Feet per Pound	Pounds per 1000 feet	Pounds per Mile	Feet per Pound	Pounds per 10 0 feet	Pounds per Mile	Feet per Pound	R Ohms per 1000 feet	Ohms per Mile	Feet per Ohm	Ohms per Pound
.....	707 160	500000 0	392700	1680	8870	59	1744	9208	57	1562	8247	64	02079	10978	48290	00001322
.....	632 455	400000 0	314160	1343	7091	74	1405	7418	76	1209	6489	81	02589	13723	38630	00002063
.....	547 722	300000 0	235620	1055	5570	94	1112	5873	90	941	4968	1 06	03465	18297	28080	00003656
0000	460 000	211600 0	166190	700	3718	1 42	746	3940	1 34	639 33	3375 7	1 56	04904	25891	20392 9	00007653
000	409 640	167805 0	131790	565	2983	1 77	599	3161	1 67	507 01	2677 0	1 97	06181	32649	16172 1	00012169
00	364 800	133079 0	104520	460	2433	2 17	493	2600	2 03	402 09	2123 0	2 49	07797	41168	12825 4	00019438
0	324 950	105592 5	82887	371	1963	2 69	397	2095	2 52	319 04	1684 6	3 14	09827	51885	10176 4	00030734
1	289 300	83694 5	65733	281	1483	3 56	299	1572	3 35	252 88	1335 2	3 95	12398	65460	8066 0	00048920
2	257 630	66373 2	52130	231	1219	4 33	248	1310	4 03	200 54	1058 8	4 99	15633	82543	6396 7	00077784
3	229 420	52633 5	41339	193	1018	5 18	207	1091	4 84	159 03	839 68	6 29	19714	1 04060	5072 5	0012370
4	204 310	41742 6	32784	152	802	6 58	162	855	6 17	126 12	665 91	7 93	24858	1 31248	4022 9	0019666
5	181 940	33102 2	25998	123	650	8 12	134	710	7 45	100 01	528 05	10 00	31346	1 65507	3190 2	0031273
6	162 020	26250 5	20617	104	550	9 60	112	595	8 87	79 32	418 81	12 61	39528	2 08706	2529 9	0049723
7	144 280	20816 7	16349	.....	.....	.....	.....	.....	.....	62 90	332 11	15 90	49845	2 63184	2006 2	0079078
8	128 490	16509 7	12966	66	352	15 00	74	387	13 65	49 88	263 37	20 05	62849	3 31843	1591 1	0125719
9	114 430	13094 2	10284	.....	.....	.....	.....	.....	.....	39 56	208 88	25 28	79242	4 18400	1262 0	0199853
10	101 890	10381 6	8153 2	48	250	21 11	52	271	19 50	31 37	165 63	31 38	99948	5 27726	1000 5	0317946
11	90 742	8231 11	6467 0	.....	.....	.....	.....	.....	.....	24 88	137 37	40 20	1 2692	6 65357	793 56	0505413
12	80 808	6529 94	5128 6	31	160	33 00	33	172	30 36	19 73	104 18	50 69	1 5890	8 39001	629 82	0803641
13	71 961	5178 39	4067 1	.....	.....	.....	.....	.....	.....	15 65	82 632	63 91	2 0047	10 5798	499 06	127788
14	64 084	4106 76	3225 4	23	118	44 74	24	125	42 24	12 41	65 525	80 38	2 5266	13 3405	395 79	203180
15	57 068	3256 76	2557 8	.....	.....	.....	.....	.....	.....	9 84	51 956	101 63	3 1860	16 8223	313 87	323079
16	50 820	2582 67	2028 6	14	76	69 47	15	80	66 00	7 81	41 237	128 14	4 0176	21 2130	248 90	513737

TABLE OF CARRYING CAPACITY OF WIRES.

UNDERWRITERS' RULES.

B. & S. G.	Table A. Rubber Insulation. Amperes.	Table B. Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,600
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

TABLE OF DIMENSIONS OF PURE COPPER WIRE.*

No. B. & S.	Diam. Mils.	Area. Circular Mils.	Area. Square Mils.	Weight and Length. Sp. Gr. 8.9. Lbs. per 1000 feet.	Lbs. per Mile.	Feet per Pound.
0000	460.000	211600.0	166190.2	640.73	3383.04	1.56
000	409.640	167805.0	131793.7	508.12	2682.85	1.97
00	364.800	133079.0	104520.0	402.97	2127.66	2.48
0	324.950	105592.5	82932.2	319.74	1688.20	3.13
1	289.300	83694.5	65733.5	253.43	1338.10	3.95
2	257.630	66373.2	52129.4	200.98	1061.17	4.98
3	229.420	52633.5	41338.3	159.38	841.50	6.28
4	204.310	41742.6	32784.5	126.40	667.38	7.91
5	181.940	33102 2	25998.4	100.23	529.23	9.98
6	162.020	26250.5	20617.1	79.49	419.69	12,58
7	144.280	20816.7	16349.4	63.03	332.82	15.86
8	128.490	16509.7	12966.7	49.99	263.96	20.00
9	114.430	13094.2	10284.2	39.65	209.35	25.22
10	101.890	10381.6	8153.67	31.44	165.98	31.81
11	90.742	8234.11	6467.06	24.93	137.65	40.11
12	80.808	6529.94	5128.50	19.77	104.40	50.58
13	71.961	5178.39	4067.07	15.68	82.792	63.78
14	64.084	4106.76	3225.44	12.44	65.658	80.42
15	57 068	3256.76	2557.85	9.86	52.069	101.40
16	50.820	2582.67	2028.43	7.82	41.292	127.87
17	45.257	2048.20	1608.65	6.20	32.746	161.24
18	40.303	1624.33	1275.75	4.92	25.970	203.31
19	35.890	1288.09	1011.66	3.90	20.594	256.39
20	31.961	1021.44	802.24	3.09	16.331	323.32
21	28.462	810.09	636.24	2.45	12,952	407.67
22	25.347	642.47	504.60	1.95	10.272	514.03
23	22.571	509.45	400.12	1.54	8.1450	648.25
24	20.100	404.01	317.31	1.22	6.4593	817.43
25	17.900	320.41	251.65	.97	5.1227	1030.71
26	15.940	254.08	199.56	.77	4.0623	1299.77
27	14.195	201.50	158.26	.61	3.2215	1638.97
28	12.641	159.80	125.50	.48	2.5548	2066.71
29	11.257	126.72	99.526	.38	2.0260	2606.13
30	10.025	100.50	78.933	.30	1.6068	3286.04
31	8.928	79.71	62.603	.24	1.2744	4143.18
32	7.950	63.20	49.639	.19	1.0105	5225.26
33	7.080	50.13	39.369	.15	.8015	6588.33
34	6.304	39.74	31.212	.12	.6354	8310.17
35	5.614	31.52	24.753	.10	.5039	10478.46
36	5.000	25.00	19.635	.08	.3997	13209.98
37	4.453	19.83	15.574	.06	.3170	16654.70
38	3.965	15.72	12.347	.05	.2513	21006.60
39	3.531	12.47	9.7923	.04	.1993	26487.84
40	3.144	9.88	7.7635	.03	.1580	33410.05

*1 mile pure copper wire 1-16 in. diam. = 13.59 ohms at 15.5° C. or 59.9° F.

1 circular mil is .7854 square mil.

CHAPTER III

Current Generation in Dynamos — Dynamos — Brushes and Commutators.

Current Generation in Dynamos. If we take a coil of wire, Fig. 15, and rapidly thrust a magnet into it, we shall observe a certain deflection of the galvanometer needle shown with it. This deflection continues only while the magnet is in motion. After

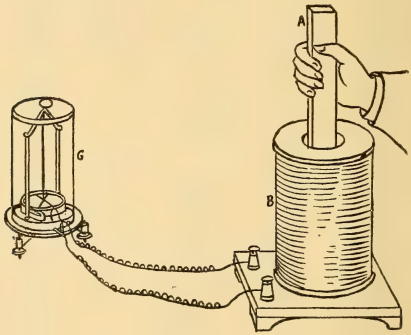


FIGURE 15.

we have inserted the magnet and it has come to rest the galvanometer needle will return to its normal position. When we withdraw the magnet the deflection of the needle will be in the opposite direction. If the magnet is inserted or withdrawn with a very quick motion, the deflection will be considerable. If the magnet is very slowly inserted or withdrawn the deflection will hardly be noticeable. The

same phenomena will occur if instead of moving the magnet, we hold it stationary and move the coil, or if both of them be moved towards or from each other. The deflection of the compass needle indicates that a current of electricity is passing along the wire, and the experiments above described show exactly how currents of electricity are produced in dynamos.

An electromotive force is induced by rapidly cutting "lines of force," that is, by moving either a magnet over a wire or a wire over or near a magnet. The

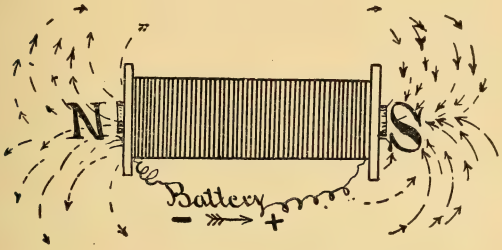


FIGURE 16.

current in turn is the result of this electromotive force acting in a closed circuit. A bar of iron becomes an electromagnet if we wind about it a few turns of wire and cause a current of electricity to flow along the wire, Fig. 16. The magnetism is conceived to consist of lines of force, which leave the bar at one end and enter it at the other, the direction of these lines depending upon the direction in which the current circulates about the bar of iron. The number of these lines of force depends upon the number of ampere turns in the iron bar and on the diameter, length and quality of the iron bar.

Ampere turns is a term used to indicate the magnetizing force; it is the number of turns of wire on a magnet multiplied by the current in amperes flowing through these turns of wire.

Haskins, in *Electricity Made Simple*, explains this thus: "If, for instance, we have a current of one ampere flowing through a single turn of wire around a bar of soft iron and we have developed enough magnetism to lift a keeper or other piece of iron, weighing one ounce, then with one-half the amount of current and two coils around the bar, we would obtain the same result, and with three turns of wire we would require but one-third the current to develop the same lifting power in the bar or magnet."

The law of magnetic flow is very much the same as the law of current flow. If the iron bar is of low magnetic resistance, the flow will be quite great; if of high resistance, the flow will be small.

Lines of force can also be shunted just as a current of electricity can; that is, they will follow the path of lowest resistance just as a stream of water or a current of electricity will.

Now let us consider the elementary sketch of a dynamo, Fig. 17. The wire *a* represents the armature and we have also the iron bar and the coil of wire wound on it and, for the present, we may consider the battery B as the source of the current which produces the magnetism or lines of force in the iron bar. The battery current magnetizes the iron bar (which in dynamos is known as the field magnet) and produces the lines of force indicated by arrows.

These lines of force leave the field magnet of our dynamo at the north pole marked N, and pass through the air-gap and armature into the south pole marked S.

As we begin to move the wire or armature, it cuts through these lines of force and begins to generate an electromotive force, which in turn will cause the current to flow if the circuit is closed through a lamp or other device.

This current reverses in direction as the wire *a* passes from the influence of the south pole into that of the north pole and the brushes B′ and B″, which transmit

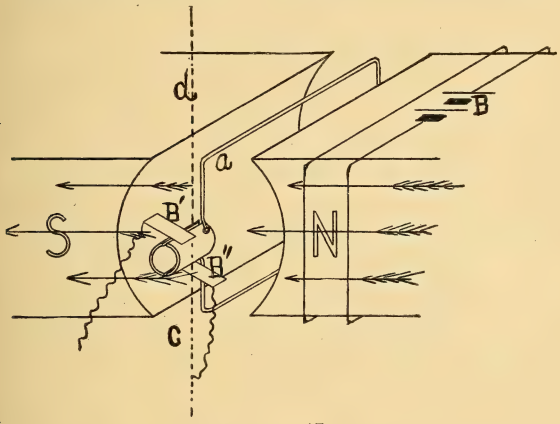


FIGURE 17.

the current to the outside wires, are so set that they change the connection of the wire *a* at the time that it passes from one pole to the other. By this means the current in the external circuit is kept constant in direction, although it alternates in the armature.

The faster we turn our wire or armature, the greater will be the electromotive force generated. Instead of using only one wire, as in Fig. 17, we may take many

turns before bringing the end out, and in so doing obtain the well known drum armature, or, by a slightly different method of winding, the gramme ring armature, Fig. 18. Here we have many wires cutting the lines of force at once and our electromotive force with the same number of revolutions of the armature is correspondingly increased, and the more turns of wire we arrange to cut those lines of force per second the greater will be our E. M. F. Instead of providing

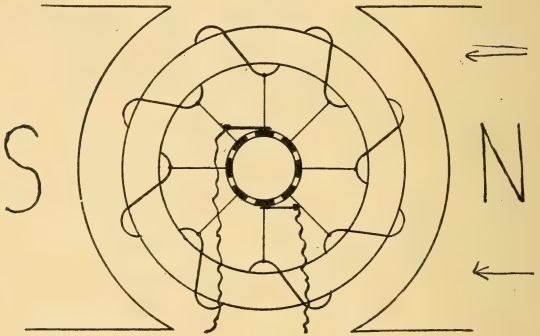


FIGURE 18.

more wire or increasing the speed of our armature we can increase the magnetism, or number of lines of force, by sending more current through the fields, that is increasing the "ampere turns."

If we wish to reverse the current flow we can do so by revolving the armature in the opposite direction, or by reversing the current through the fields.

Dynamos. Having so far considered the generation of currents in dynamos, we may now consider different types of dynamos and their uses. Fig. 19 shows a dia-

gram of the wires and connections of a series dynamo. The principal use of this dynamo at present is in connection with series arc circuits. (See Fig. 7.) This dynamo is usually equipped with an automatic regulator (which will be explained later) to raise or lower the voltage as the number of lamps increases or

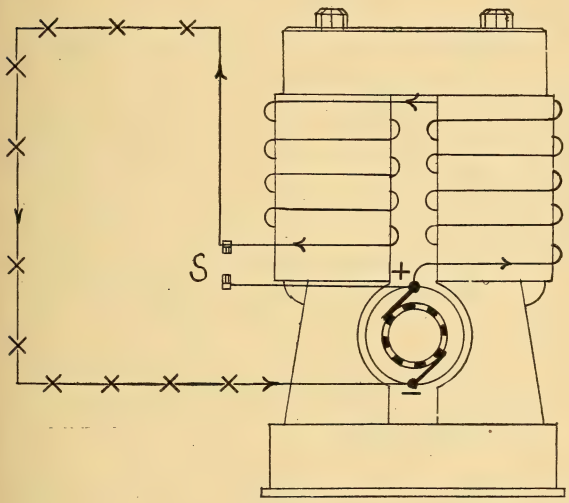


FIGURE 19.

decreases, the current remaining constant at about 10 amperes. By reference to the figure, we can trace the current as it flows from the + brush, in the direction of the arrows, around both field magnets and through the lamps, returning to the – brush on the dynamo. In our elementary sketch of a dynamo we used battery current to magnetize our fields; we need not consider

that any more, for in practice all direct current dynamos produce their own magnetism by circulating some or all of their current through the field coils.

In the shunt wound dynamo, Fig. 20, the wire in the field winding is of such size and connected in such a manner as to have a resistance so high that only a

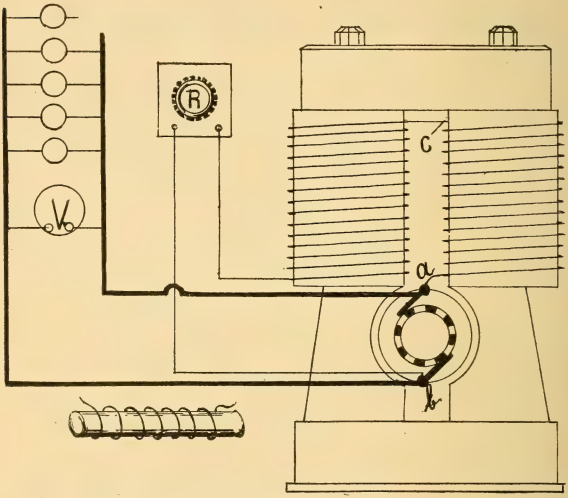


FIGURE 20.

portion of the main generated current of electricity passes around the field magnets. The quantity of current passing around these field magnets is also regulated by a resistance sometimes called a rheostat shown at R. The resistance to the flow of current through this box is adjusted by hand by the attendant and the flow of current through this rheostat and around the

field magnet is what determines the electromotive force of the dynamo.

This type of dynamo is used for electric lighting and for operating motors. The electromotive force of such a dynamo remains nearly constant, but the current varies with the number of lights or motors used. If it were connected to too many lights it would deliver too much current and become overheated and perhaps burn out. The current leaves at the + brush, passes through whatever lamps happen to be switched on and returns to the − brush.

Fig. 21 shows a diagram of a compound wound dynamo. This is really a combination of the series and shunt dynamos. If the current in a series dynamo is not kept constant the magnetism in the fields will vary as the current varies, and consequently its voltage will be very unsteady. This makes such a dynamo unfit for use with variable currents.

The voltage of a shunt dynamo is quite constant with variable loads, but still it leaves much room for improvement; not because of any variation in the induced electromotive force, but because of the losses occurring in the armature and wires conveying current. The loss of voltage in the armature and line equals the current multiplied by the resistance; consequently, as the current increases more and more volts are lost and the pressure goes down. If we would have the pressure remain at its normal value, we must find some way to increase the field magnetism as the current delivered by the dynamo increases, and this is the purpose of the compound winding. The compound winding carries the total current of the dynamo around the fields, but only a few times, just often enough so that the increase in magnetism resulting from this current may

make up for the loss in the armature or line. Dynamos may be compounded for any per cent. of loss desired.

The foregoing descriptions are those of direct current dynamos, and they are called direct or continuous

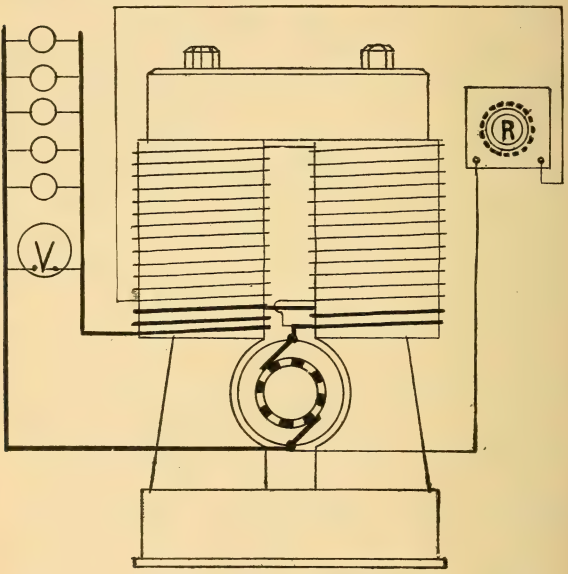


FIGURE 21.

current dynamos because the current flow continues in one direction out of the positive or + side of the dynamo, to the external circuit, and back again to the negative or – side of the dynamo. The current as it is generated in the coils of the armature which

revolves between the field or pole pieces, is alternating; that is to say, if the armature wires were connected to collector rings the current in the outside wires would be reversed every time the position of the wire in the armature were changed from the influence of one pole piece to that of the other. If the coils constituting the armature are connected to a device called the commutator, they will be commutated or rectified.

Such a commutator is formed of alternate sections of conducting and non-conducting material, running parallel with the shaft with which it turns. It is

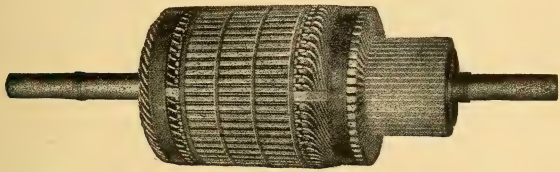


FIGURE 22.

placed on the shaft of the armature so that it rotates with it, as shown in Fig. 22. The brushes press upon its surface and collect the current from the bars. (See Fig. 31.) The function of the commutator is to change the connections of the armature coils from the + or positive to the negative or – side of the circuit at the time at which the coil connected to the bar under the brush passes from the influence of one pole piece into that of the other. This is the time at which the current in the coil reverses in direction, and is called the neutral point. If we consider, for the sake of simplicity, an armature having only one turn of wire on it, as Fig. 17, there will be a time while the coil is in the

position indicated by dotted lines at *c* and *d* when no current is being generated. The brushes on any dynamo should always be set at this point, for this is the point of least sparking. In actual practice all commutators have quite a number of bars and it is impossible to avoid, in passing under the brushes, that at least two of them are in contact with a brush at the same time. If a brush did leave one bar before it touches another, the current would be entirely broken for that length of time and much sparking would result. The nature of all armature windings is such that while the brush is in contact with the commutator bars it short circuits that coil between them. This is the main reason why the brushes must be kept at a point at which the coil which is short circuited generates no current.

Although the electromotive force generated in one coil of a dynamo is very small, the resistance of the "short circuit" formed by the dynamo brush is also very small and therefore the current may be quite large. This current is the main cause of sparking in dynamos. The number of bars constituting a commutator depends upon the winding of the armature, and the number of coils grouped thereon. By increasing the number of coils and commutator sections the tendency to spark at the brushes is decreased, and the fluctuations of the current are also decreased. However, there are many reasons against making the number of bars on a commutator very great. Increasing the number of bars in a commutator increases the cost of manufacture, and in smaller dynamos if the number of bars be increased beyond a certain extent, each bar becomes so thin that a brush of the proper thickness to collect the current from the commutator would lap over too many

bars of the commutator at one time. Each commutator bar should be of the size that will present sufficient metal for the carrying capacity of the current generated in the coil to which it is connected. Different builders of dynamos have different ideas as to the number of amperes that may be carried per square inch in a commutator bar, but where a commutator is made

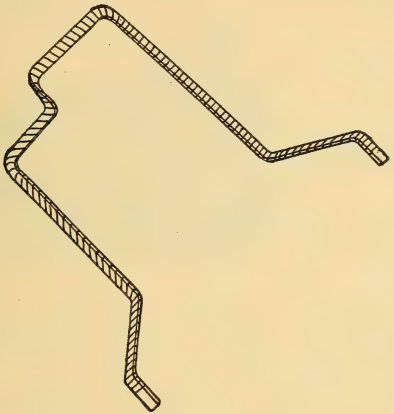


FIGURE 23.

of 95 per cent. copper it is usual to allow for each 100 amperes a commutator bar surface of 1½ sq. in.

The method of electrical connection between the commutator bar and the coil of the armature varies in different designs. Some builders solder the terminals of the coils to the commutator bars; others bolt the terminals of the coils to the bars; and some makers use hard drawn copper and "form" the armature coil in such a manner that both ends of the coil become

commutator bars, making the coil continuous from one end of the commutator bar to the end of the diametrically opposite commutator bar.

In Fig. 23 we show a so-called "formed" armature coil, after it has been prepared by properly insulating it and bending it into shape ready to be applied to the laminated armature body.

In Fig. 24 is shown a "formed" coil armature with

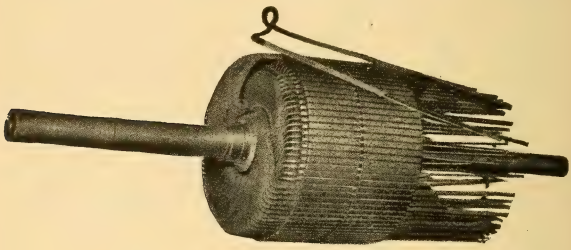


FIGURE 24.

the winding almost finished. The commutator is yet to be placed on the shaft and the coil terminals connected to the commutator bars.

In Fig. 25 we have an armature shaft with the lami-

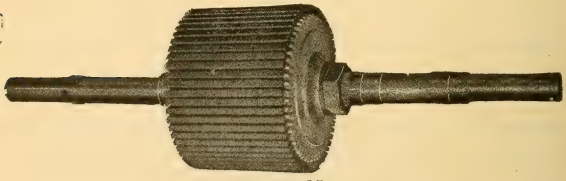


FIGURE 25.

nated armature body keyed on to the shaft ready to be wound.

The body on which the armature coils are to be wound is made up of sheet iron punchings and placed on the armature shaft in the same manner that you would put ordinary iron washers on a lead pencil. These punchings or discs are insulated from one another by having previously been painted with a coat of shellac; for there is the same tendency to produce current in the iron part of the armature, due to the cutting of the magnetic lines, as there is in the copper wire which is wound on its surface. If the iron core were solid, there would be a very large current circulating in the same direction as that which flows through the wires. Such a current would be entirely useless and would heat the armature; to prevent this the armature is built up of thin sheet iron discs.

Brushes and Commutators. Figs. 26 to 30 show different arrangements of modern brushes and brush-holders. These are used to take the current from the commutator and deliver it to the outside wires in the case of a dynamo, and for the opposite in the case of a motor.

There are many different designs and constructions of brushes and brush-holders, and these designs are brought about by the various ideas of different builders in their attempt to produce various advantageous results, but the electrical connections and underlying principles remain the same whether a copper or a carbon brush be used.

In any construction of brush holding device, if great care is not exercised in keeping it thoroughly clean, trouble is sure to be the result, and trouble of this nature increases so rapidly that unless the attendant immediately sets about to right it, a burned out armature is almost sure to be the consequence sooner or later. In alternating current dynamos, where brushes

rest on collector rings instead of commutators, it is much easier to keep out of trouble, because the brushes in this case merely collect the current from the rings and do not commutate or rectify it.

The brushes and commutator of a dynamo or motor

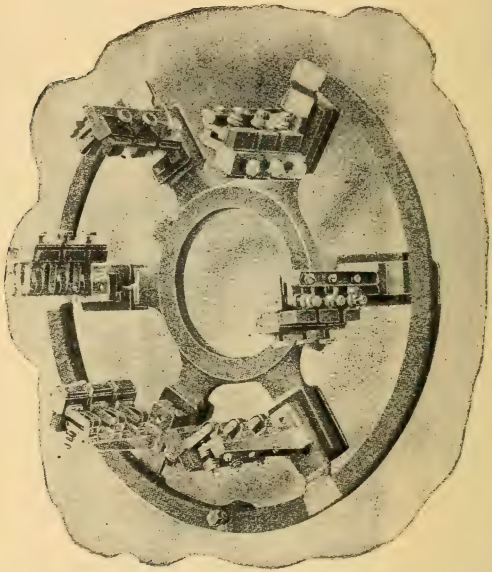


FIGURE 26.

are probably the most important parts with which the engineer has to deal. Great care should be taken that the brushes set squarely on the commutator and that the surface of the brushes and commutator are as smooth as possible. It is a good plan, and in some

cases the brush-holders are so made, that the brushes set in a staggering position, that is to say, in a position so that all the brushes will not wear in the same place over the circumference of the commutator and

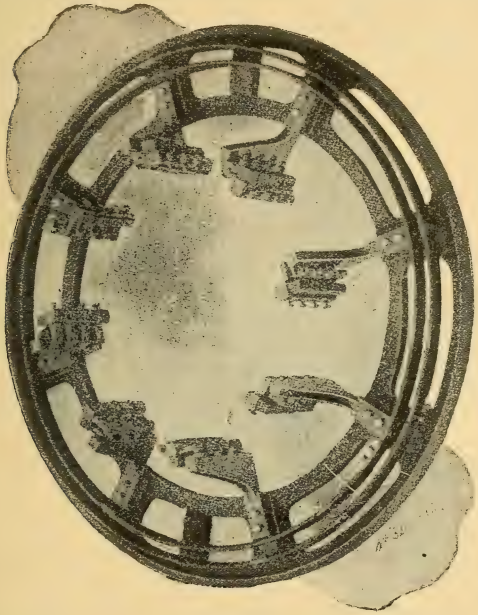


FIGURE 27.

cause uneven wear across the length of the commutator bars. In most machines the armature bearing is left so that there is more or less side motion, which, when the armature is running, causes a constant changing of the position of the brushes and commutator.

Whatever style of brush is used, the commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary unless the brushes cut, and then only at the point of cutting. A cloth (not cotton waste) slightly greased with vaseline and applied to the surface of the commutator while

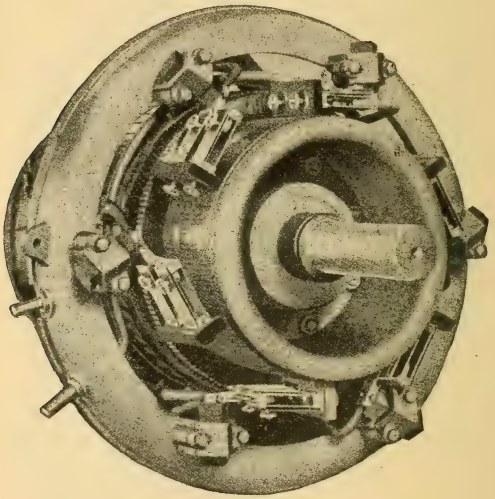


FIGURE 28.

running is best for the purpose of preventing the commutator from cutting. Should the commutator become rough, it should be smoothed with sandpaper, never using emery cloth, because emery cloth is conductor of electricity, and the particles of emery are liable to lodge themselves between the commutator bars in the mica and short circuit the two bars, thereby

burning a small hole wherever such a particle of emery has lodged itself. The emery will also work into the brushes and copper bars and wear them down; it being almost impossible to remove all the emery.

In the end-on carbon brushes, Fig. 30, the contact surface of the brushes should be occasionally cleaned by taking a strip of sandpaper, with the smooth side of the paper to the commutator, and the sanded side toward the contact surface of the brush, and then by

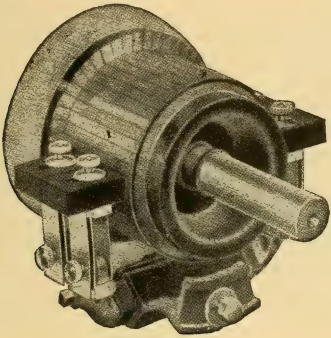


FIGURE 29.

leaving the tension of the brush down on the sandpaper, it is an easy matter to move the sandpaper to and fro and throughly clean off the glazed and dirty surface from the carbon, leaving it with a concave that will exactly fit the commutator.

The advantages of carbon brushes are many. Among the cardinal points are: The armature may run in either direction without it being necessary to alter the brushes; the carbon can be manufactured with a quantity of graphite in its construction, thereby

lowering the mechanical friction of the brushes on the commutator; they do not cut a commutator so much by sparking; the commutator has a longer life, the wear being more evenly distributed.

Carbon brushes, due to their rather high resistance, will often heat up considerably, but, although this heat is objectionable, their resistance tends to cut down the sparking. The brushes are sometimes coated with copper to reduce their resistance. Often a car-

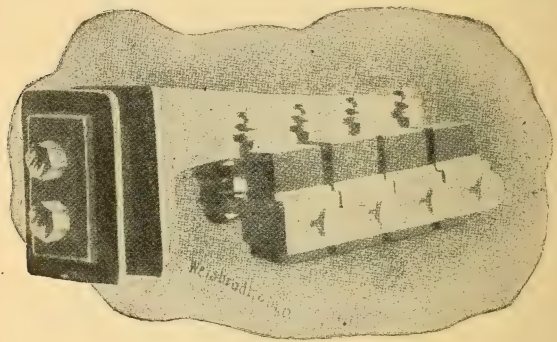


FIGURE 30.

bon brush will be found which is very hard. As a rule such a brush should be thrown away, as it will heat abnormally and at the same time wear the commutator.

In Fig. 31 we have one of the various so-called old styles of leaf brush-holders. The end-on brushes are more generally used in modern practice, because their contact surface area is not increased or decreased by wear. Consequently the brushes always remain in a diametrically opposite position. With the old style

brush-holding device, where the brushes rest on the commutator at a tangent, great care should be exer-

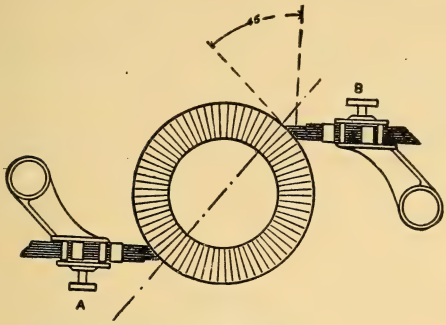


FIGURE 31.

cised not to allow the brushes to wear in a position so that their points will be out of diametrical opposition.

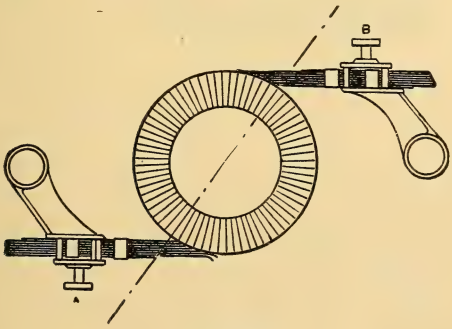


FIGURE 32.

In Fig. 31 we show the correct way that this type of brush should be set.

In Figs. 32 and 33 we show the incorrect way.

By remembering that each one of the commutator bars is the end of a coil, and then just mentally tracing the current through the coils from one brush to the other, we can readily understand what the results are when the brushes are neglected and left in a relative position, as shown in these figures.

Sparking is the usual result of brushes allowed to wear to such an extent. Overloading of a dynamo or motor will also cause serious sparking, and no amount

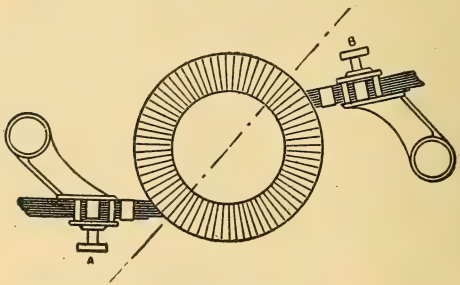


FIGURE 33.

of care can prevent damage to armature, commutator or brushes, if a machine is permitted to be overloaded.

Sometimes the commutator will contain one or more bars which, as the commutator gets old and wears down, will wear away either too fast or too slow, due to the metal being harder or softer than the rest of the bars forming the commutator. This causes a roughness of the commutator and results in the flashing of the brushes and heating of both the commutator and brushes. About the only satisfactory method of

remedying this evil is to take out the armature and have the commutator turned down in a lathe.

A short-circuited coil in the armature, or a broken armature connection, will also cause considerable sparking. Either of these conditions can be located by means of a Wheatsone bridge or by what is known as the fall of potential method. To make a test with this latter method, connect in series with the armature to be tested some resistance capable of carrying the necessary current, also an ammeter. Some apparatus for varying the current strength, such as a water rheo-

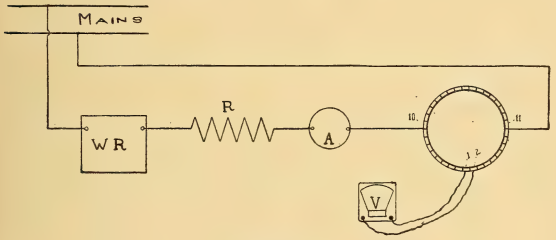


FIGURE 34.

stat or lamp rack, must be connected in the circuit, a diagram of which is shown in Fig. 34.

In the diagram, WR is the water rheostat or lamp rack, R the known resistance, A the ammeter and M the armature to be tested. By means of the water rheostat regulate the current passing over the apparatus until it is of such strength that a deflection can be obtained on a voltmeter when it is connected to two adjacent bars on the commutator. Suppose the armature coil between bar 1 and 2 on the commutator were broken. The voltmeter connected across these two bars would give the same reading as when connected

across the two points 10 and 11. If the voltmeter were connected between any other two points on the commutator on the same side as the broken coil no deflection would be obtained, while connecting the voltmeter between any two adjacent bars on the other side of the commutator would give practically the same reading irrespective of which bars were used. The resistance of one or more sections of the armature winding could also be found by using Ohm's law, $R = E/C$, or the resistance would be equal to the voltage divided by the current as shown on the ammeter. It must be remembered that this latter will be true only when there is an open coil in one side of the armature, for in this case only will the whole current flow through the one side. If the coil between bars 1 and 2 were short circuited, the voltmeter would show practically no reading between these bars; while between any other bars some deflection would be obtained. An open circuit or short circuit will nearly always be found by examination, as the trouble usually happens very close to the commutator connections in the case of an open circuit and may very often be found between the commutator bars themselves, in the case of a short circuit. If the trouble is not at these places it will usually be in the windings, in which case the only remedy is to have it re-wound. Temporary repairs may be made in the case of an open circuit by short circuiting the commutator bars around the open circuit, but this method should only be used in emergency, as the sparking will in time destroy the commutator.

With many dynamos, especially of older types, it is necessary to shift the brushes with every change of load. The current produced by the armature makes a magnet out of it and the magnetism of the armature

opposes that of the fields. In Fig. 35 the armature is working with a very light load and the lines of force of the field magnets are only slightly opposed by those

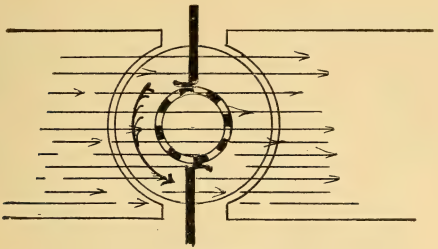


FIGURE 35.

of the armature. In Fig. 36 we assume a heavy load on the dynamo and consequently the magnetism of the armature opposes that of the fields. This changes the location of the neutral point (when the coils under the brush generate no current) and it becomes necessary to

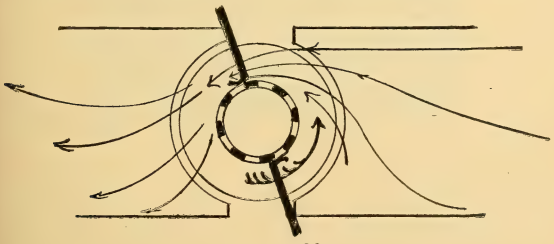


FIGURE 36.

shift the brushes accordingly, or great sparking would result. The amount of shifting necessary with changes of load varies in different dynamos. If the field is

very strong compared to the armature, it will be but little. If the armature (as in some arc dynamos) is very strong compared to the field, it will be considerable.

In dynamos, with increasing load, the brushes should be shifted in the direction of rotation and in the opposite direction when the load decreases.

Never allow a dynamo or motor to stand in a damp place uncovered. Moisture is apt to soak into the windings and cause a short circuit or ground when started. Great care should also be used should it ever be found necessary to use water on a heated bearing. If the water is allowed to reach the armature or commutator, it is bound to cause trouble. Water should only be used in case of emergency, and then sparingly.

CHAPTER IV

OPERATION OF DYNAMOS

Constant Potential Dynamos. In order to thoroughly explain the operation of dynamos, let us assume that we have the task of starting a new shunt dynamo, one that has never generated any current. Our first step is to open the main switch and turn the rheostat or field

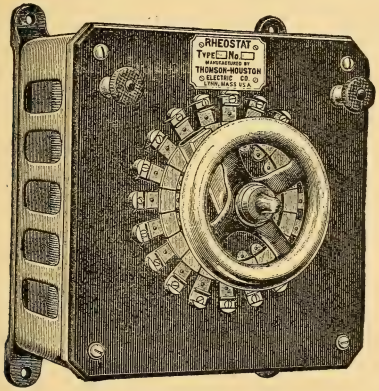


FIGURE 37.

resistance box so that all the resistance is in circuit. A rheostat consists of a number of resistances, Fig. 37, so arranged that they can be cut in or out of the circuit without opening the circuit. By reference to the figure it will be seen that the current enters at the handle and from there passes to the contact point upon which the

handle happens to rest. If the handle is at 1 the current must pass through all the wire in the box; if it is at 2 it simply passes through the handle and out.

Rheostats for the shunt circuit of a dynamo should have sufficient resistance, so that when it is all inserted the voltage of the dynamo will slowly sink to zero. This method of stopping the action of a dynamo is

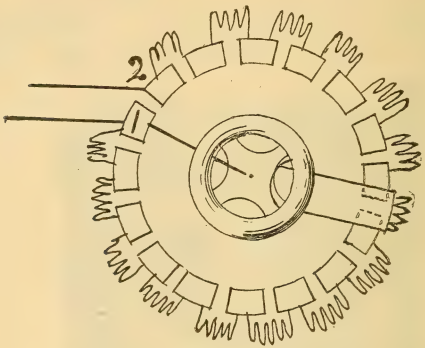


FIGURE 37.

perfectly safe and should be followed wherever possible.

We are now running our dynamo with all resistance in the shunt circuit. This is simply as an extra precaution because we know nothing about this particular dynamo. When it is known that the dynamo is in good order, the engineer or attendant usually cuts out all the resistance, and as the generator builds up or, in other words, generates current, he proceeds, by the aid of the resistance box, to cut down or diminish the flow of electricity around the field magnets of the dynamo,

and thereby diminish the magnetic density of the field magnets and the electromotive force of the dynamo.

We must now gradually turn our rheostat so as to cut out resistance and watch the voltmeter, which is connected as shown at V in Fig. 20, and receives current whenever the dynamo is operating. Suppose that the voltmeter indicates nothing, and we find that the dynamo will not generate. On examination of all the connections we find everything correct, and we now discover that the dynamo field magnets do not contain what is termed "residual magnetism" sufficient to start the process of generating current.

Before an armature can generate current it must cut lines of force, that is, it must revolve in a magnetic field. If the dynamo has been generating current it is likely that the iron cores of the field magnets will retain sufficient magnetism to start the generation of current again. This magnetism which remains in the iron is known as residual magnetism. It will make itself manifest by attracting the needle of a compass, or if strong, a screw driver or a pair of pliers. If we find no magnetism in the iron core of the field magnets, we may take the ends of the shunt winding on the field magnets and pass current over them from a battery. This current will produce sufficient magnetism to cause the generator to build up; in other words, if we disconnect these batteries, and connect the wires back again from where we got them, we will find that we can generate current with the machine.

When the machine begins to generate, we watch the voltmeter and cut resistance in or out of the circuit according whether we need to lower or raise the voltage. If we have only one dynamo we may close the

main switch before we begin generating or after we have attained full voltage.

Again referring to the pole pieces on the dynamo, it is possible that there is a sufficient quantity of residual magnetism in the pole pieces, and that the polarity of both field magnets, between which the armature is revolving, is the same. This would also cause the dynamo to fail in generating current. If sending battery current through the coils does not make one field a north pole and the other a south pole, one of the fields must be connected wrong, and we must make some changes in the connection.

Referring to Fig. 20, a and b are the terminals of the shunt winding on the fields. If the winding of the fields is correctly put on it will be as in the little sketch at lower corner; that is, if both field magnets were taken out of their places and put together, the winding should run as one continuous spool. But if the winding on one field is wrong, we need simply change its connection, as, for instance, transferring c to a and a to c.

In order that a dynamo may excite itself, it is necessary that the current produced by the residual magnetism shall flow in such a direction as to strengthen this residual magnetism. If the current produced by the residual magnetism flows through the field coils in the opposite direction this will tend to weaken the residual magnetism and consequently to reduce the current which flows.

For this reason if the first attempt to start a dynamo with battery current fails, the battery should be applied with the opposite poles so that the magnetism it produces in the fields will be in the opposite direction.

The magnetism, the fields, and all parts of the

dynamo may be in perfect working order and yet a short circuit in any part of the wiring will prevent the dynamo from building up This short circuit will furnish a path of such low resistance that all current will flow through it and none can flow through the fields to induce magnetism. Often dynamos fail to generate because of broken wires in the field coils, poor contacts at brushes, or loose connections. Sometimes also part of the wiring may be grounded on the metal parts of the dynamo frame. A faulty position of the brushes may also be a cause for the machine not generating. In some machines the proper position for the brushes is opposite the space between the pole pieces, while in other machines their proper position is about opposite the middle of the pole piece. If the exact position is not known, a movement of the brushes will sometimes cause the generator to build up.

If there are several dynamos to be started great care must be taken to see that the second machine is operating at full voltage before the switch is closed connecting it to the switch board. The voltage should be exactly the same as that of the first machine and the rheostat worked to keep it so. If it is less, it is possible that the first machine will run the second as a motor; if it is more, the second machine may run the first as motor, the machine having the higher voltage will always supply the most current.

It is also necessary before throwing in the second machine (connecting it to the switch board) to see that its polarity is the same as that of the machine with which it is to run. By reference to Fig. 38 it will be seen that the + poles of both machines connect to the same bar, and if one of these machines is running and we wish to connect the other with it, we must first be

sure that the wire of the second machine which leads to the top bus-bar is of the same polarity. That is, if the top bus-bar is positive, or sends out current, the wire of all dynamos connected to it must also be positive. The simplest way to find the positive pole of a dynamo is with a cup of water. Take two small wires and connect one to each of the main wires of the dynamo and then insert the bare ends of both wires into the water, small bubbles will soon be seen to rise in the water from one of the wires. That wire which gives off the bubbles is the negative wire. Take care that in making this test you do not get the ends of the small wires together or against the metal of the cup or you will form a short circuit. The polarity of both dynamos must be tested and wires of same polarity connected to the same bus-bar.

Where several machines are to be operated in parallel, compound dynamos are generally used, because it is troublesome to keep two shunt machines working in harmony.

The starting of a compound wound dynamo is the same as that of a plain shunt dynamo, but in connecting a compound wound dynamo to its circuit it is necessary to be sure that the shunt coils and series coils tend to drive the lines of force around the magnetic circuit in the same direction. If the series coil is connected up in the opposite direction to the shunt coil the dynamo will build up all right and will work satisfactorily on very light loads. When, however, the load becomes even, five or ten per cent. of full load, the voltage drops off very rapidly and it is impossible to get full voltage with even half the load on. This is because the ampere turns due to the series coils decrease the total ampere turns acting on the magnetic

circuit instead of increasing them as the load comes on. This lowers the magnetic flux and of course lowers the resulting voltage. In such a case it will be necessary to reverse either the field or series coils.

Fig. 38 and the following description of compound dynamos and their connections is taken from *Wiring Diagrams and Descriptions*, by Horstmann and Tousley, published by Frederick J. Drake & Co., Chicago.

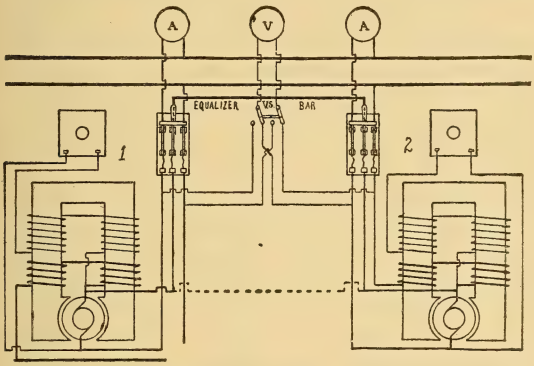


FIGURE 38.

Fig. 38 shows connections for two compound wound dynamos run in parallel. When two or more compound wound dynamos are to be run together, the series fields of all the machines are connected together in parallel by means of wire leads or bus-bars which connect together the brushes from which the series fields are taken. This is known as the equalizer, and is shown by the line running to the middle pole of the dynamo switch. By tracing out the series circuits it

will be seen that the current from the upper brush of either dynamo has two paths to its bus-bar. One of these leads through its own fields, and the other, by means of the equalizer bar, through the fields of the other dynamo. So long as both machines are generating equally there is no difference of potential between the brushes of No. 1 and No. 2. Should, from any cause, the voltage of one machine be lowered, current from the other machine would begin to flow through its fields and thereby raise the voltage, at the same time reducing its own until both are again equal. The equalizer may never be called upon to carry much current, but to have the machines regulate closely it should be of very low resistance. It may also be run as shown by the dotted lines, but this will leave all the machines alive when any one is generating. The ammeters should be connected as shown. If they were on the other side they would come under the influence of the equalizing current and would indicate wrong, either too high or too low. The equalizer should be closed at the same time, or preferably a little before the mains are closed. In some cases the middle, or equalizer, blade of the dynamo switch is made longer than the outside to accomplish this. The series fields are often regulated by a shunt of variable resistance. To insure the best results compound machines should be run at just the proper speed, otherwise the proportions between the shunt and series coils are disturbed.

GENERAL RULES

1. Be sure that the speed of the dynamo is right.
2. Be sure that all the belts are sufficiently tight.
3. Be sure that all connections are firm and make good contact.
4. Keep every part of the machine and dynamo room scrupulously clean.

5. Keep all the insulations free from metal dust or gritty substances.

6. Do not allow the insulation of the circuit to become impaired in any way.

7. Keep all bearings of the machine well oiled.

8. Keep the brushes properly set and see to it that they do not cut or scratch the commutator.

9. If the brushes spark, locate the trouble and rectify it at once.

10. The durability of the commutator and brushes depends on the care exercised by the person in charge of the dynamos.

11. At intervals the dynamos must be disconnected from the circuit and thoroughly tested for leakage and grounds.

12. In stations running less than twenty-four hours per day, the circuit should be thoroughly tested and grounds removed (if any are found) before current is turned on.

13. Before throwing dynamos in circuit with others running in multiple, be sure the pressure is the same as that of the circuit; then close the switch.

14. Be sure each dynamo in circuit is so regulated as to have its full share of load, and keep it so by use of resistance box.

15. Keep belting in good order; when several machines are operating in parallel and a belt runs off from one, the others will run this machine as a motor.

16. In the same way if you shut down an engine driving a generator, the other generators will run the generator and the engine.

Constant Potential Switchboard. In Fig. 39 we show the usual type of switchboard employed to connect, or switch various dynamos and to feed various circuits from. These types, sizes and arrangements of switchboards vary and depend entirely on the type and size of the plant, the number of dynamos used and the number of circuits to be controlled. The switchboard in this cut has three dynamo panels and one load panel. At the left of the board and near the top is the voltmeter, while on the three left panels are the dynamo main switches and their respective amperemeters. On the lower part of these three machine panels will be

noticed the protruding hand wheels of the field resistance boxes, which are hidden back of the board. The meter at the top of the right hand panel is the load amperemeter and registers the total number of amperes

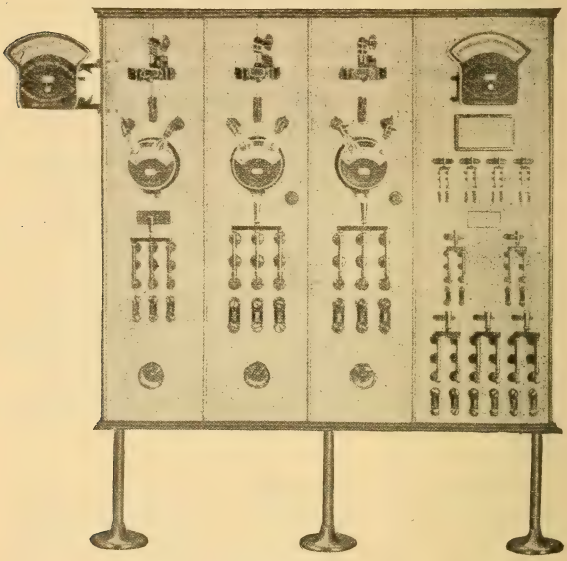


FIGURE 39.

that are being supplied to the circuits whose several switches are just below the meter.

Fig. 40 shows diagrammatically the reverse side of a similar switchboard. Below all of the switches there are installed fuses in each wire. The object of these fuses is to protect the wires and also the dynamos. These fuses consist of an alloy which melts at a com-

paratively low temperature. If, for instance, a short circuit occurs in any line, the current will suddenly become very great and will generate considerable heat. This heat will cause the fuse to melt and open the circuit. If the fuse did not melt the current would continue and overheat the wires, causing considerable

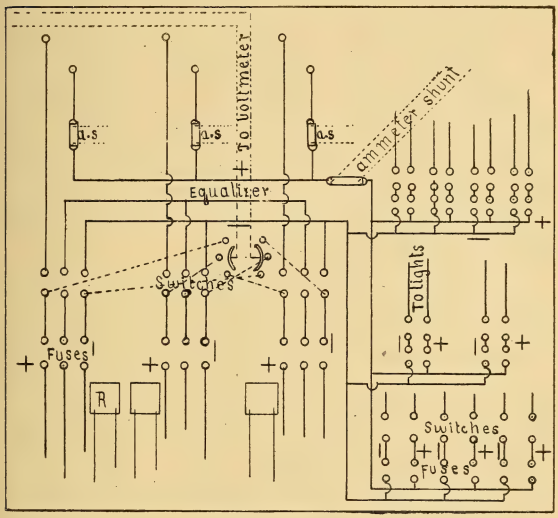


FIGURE 40.

damage and perhaps fires. The fuses should always be chosen of such a size that they will melt before the current rises enough to do any damage.

Operation of Constant Current Dynamos. Constant current dynamos differ from constant potential dynamos mainly in the higher voltage for which they are usually

constructed. Such machines are always more or less dangerous to life, and great care must be taken not to touch any of the current-carrying parts with bare hands.

When such parts must be handled rubber gloves are very convenient and useful if kept dry. High voltage machines should always be surrounded by insulating platforms of dry wood, or rubber mats, so arranged that one must stand on them in order to touch any part of the machine. By reference to Fig. 19 it will be seen that the constant current dynamo is not equipped either with a voltmeter or a field rheostat; but an amperemeter should always be used. The troubles encountered with these dynamos are much the same as those of constant potential dynamos. Most of them are referred to in the following descriptions and instructions for different systems and to avoid repetition need not be mentioned here.

The type of dynamo generally used with constant currents is shown in Fig. 19 and is series wound; that is, the same current that passes through the lights also passes through the fields and excites them. The fields of this dynamo are connected with a short circuiting switch, S, which is generally used when the machine is to be shut down. When this switch is closed it forms a path of much lower resistance than do the fields of the dynamo and all current passing through it and the dynamo loses its magnetism and stops generating. A constant potential dynamo will not begin generating if there is a short circuit anywhere in the wiring connected with it, but with the constant current dynamo it is often necessary to provide a short circuit in order to start it. If there is very much resistance in the line or if it is entirely open the dynamo will fail to generate.

. In order to start generation a small wire may be attached to one of the terminals of the dynamo and the other end brought in contact with the other terminal for a fraction of a second or the shortest possible instant. If the circuit happens to be arranged somewhat as shown in the figure, the plug may be inserted so that the dynamo is started through only one lamp. When this lamp is burning properly the plugs may be suddenly withdrawn and the current will now force itself through the other lamps. This process is known as "jumping in" and should be used only in an emergency, as much damage may be caused, especially if a dynamo is already running a large number of lamps and is then "jumped into" a bad circuit. This is also often done, but is just as dangerous as it would be to attempt to start a heavy steam engine by opening up the throttle valve with a quick jerk.

Constant current dynamos are always equipped with automatic regulators and before the dynamo is started special attention must be given the regulator to see that it is in proper working order.

Often it may be desirable and even necessary to run two dynamos in series, as, for instance, if a circuit has been extended beyond the capacity of one machine. In such a case the regulator of one machine is cut out and that machine set to operate at about its highest electromotive force, and the variations are taken care of by the other dynamo.

The Brush System. The brush arc dynamo is quite distinct from other constant current dynamos in general use. We shall therefore give the following description of it taken from literature furnished by the General Electric Company.

The brush arc generator is of the open coil type, the

fundamental principle of which is illustrated in Fig. 41. Two pairs of coils, placed at right angles on an iron core, are rotated in a magnetic field. The horizontal coils represented in the diagram are producing their maximum electromotive force, while the pair of coils at right angles to them is generating practically no electromotive force. The brushes are placed on the segments of the four-part commutator, so as to collect only the current generated by the two horizontal

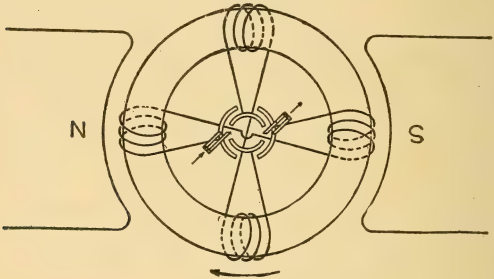


FIGURE 41.

coils. The other coils are open circuited or completely cut out of the circuit.

Such a machine will generate current, continuous in direction, but fluctuating considerably in amount. These fluctuations will be diminished by the addition of more coils to the armature.

Fig. 42 shows the connections of an eight-coil brush arc generator. Each bobbin is connected in series with the one diametrically opposite. The connection is not shown on the diagram. It will be noticed that of those coils connected to the outer ring on which the brushes A and A^1 bear, only 3, 3^1 are in circuit, 1, 1^1

being entirely cut out; while on the inside ring all coils 2, 2^1 and 4, 4^1 are in circuit, the two pairs being parallel; 4, 4^1 are coming into the field of best action; in other words, they are approaching that part of the field in which there is most rapid change of magnetic flux, while 2, 2^1 are approaching that part in which the flux is uniform. In 4, 4^1 there is an increasing electro-

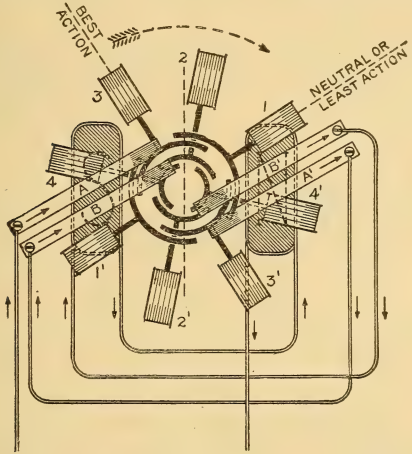


FIGURE 42.

motive force being generated, and the current is rising; while in 2, 2^1, the electromotive force is decreasing and the current falling. Unless 2, 2^1 were cut out of the circuit, a point would soon be reached where the electromotive force in 2, 2^1 would be zero, and consequently 4, 4^1 would be short circuited through 2, 2^1. Just before this occurs, however, 2, 2^1 have passed from under the brush and the small current still flowing

draws out the spark one sees on the commutator of all open coil machines.

Setting the Brushes. A pressure brush should always be used over the under brush in the same holder, as it improves the running of the commutator and secures better contact on the segment. The combination is referred to as the "brush." The brushes should be set about 5⅛ in. from the front side of the brass brush-holder.

In setting the brushes, commence with the inner pair and set one brush about 5⅛ in. from the holder to tip of the brush, then rotate the rocker or armature until

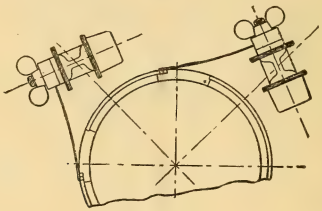


FIGURE 43.

the tip of the brush is exactly in line with the end of a copper segment, as shown in Fig. 43. The other brush should be set on the corresponding segment 90° removed (the same relative position on the next forward segment); but if the length of the brush from the holder is less than 5⅛ in., move both brushes forward until the length of the shorter brush from the holder is 5⅛ in. Now set the two extreme outer brushes in the same manner, clamping firmly in position, and by using a straight edge or steel rule, all the brushes can be set in exactly the same line and firmly secured. The spark on one of the six brushes may be a trifle

longer than on the others. In this case, move the brush forward a trifle so as to make the sparks on the six brushes about the same length. Equality in the spark lengths is not essential, but it gives at a glance an indication of the running condition of the machine.

Brushes should not bear on the commutator less than ⅛ in. from the point of the brush, or, as illustrated in Fig. 44 (a), they will tend to drop into the commutator slots and pound the copper tip of the wood block, causing the fingers of the brushes to break off. If, on the other hand, the bearing is too far from the end, or the brushes are set too long, as in Fig. 44 (b), the

FIGURE 44A.

FIGURE 44B.

FIGURE 44C.

point of the brush will not be in contact with the segment, thereby prolonging the break, and allowing the spark to follow the tip with consequent burning of the segments and brushes.

Fig. 44 (c) shows correct seating with the tip of the brush nearly tangential and stiff on the segment as it leaves.

Care of Commutator. If the commutator needs lubrication, oil it very sparingly. Once or twice during a run is ample. If the oil has a tendency to blacken the commutator instead of making it bright, wipe the commutator with a dry cloth. Too much oil causes flashing.

The machine, of course, generates high potential, and the cloth, or whatever is used to oil the commu-

tator, should therefore be placed on a stick so that the hand is not placed in any way between the brushes.

A rubber mat should be provided for the attendant to stand on when working around the commutator or brushes.

One hand only should be used, and great care exercised not to touch two brush clamps or brushes at the same time; never with switches closed.

As soon as current is shut off from the machine the commutator should be cleaned. A piece of very fine sandpaper held against the commutator under a strip of wood for about a minute before the machine is stopped, will scour the commutator sufficiently. The brushes need not be removed. An effort should be made to have the machine cleaned immediately after it is shut down. Five minutes at that time will give better results than half an hour when the machine is cold. Never use a file, emery cloth or crocus, on the commutator. New blocks will sometimes cause flashing, due to the presence of sap in the wood. The machine should be run for a few hours with a slightly longer spark, say ½ in., and the commutator then thoroughly cleaned with fine sandpaper.

All constant current arc machines require an automatic regulator to increase the voltage as more lamps are cut into the circuit and decrease it as lamps are cut out.

We will give only one of the several forms of regulators used with this system.

The form 1 regulator is placed on the frame of the machine beneath the commutator, and a constant motion is imparted to its main shaft through a small belt running around the armature shaft. (See Fig. 46.) By means of magnetic clutches and bevel gears,

a pinion shaft is rotated, which moves the rack and the rocker arm and so shifts the brushes on the commutator to maintain a spark of about 3/8 in. on short cir-

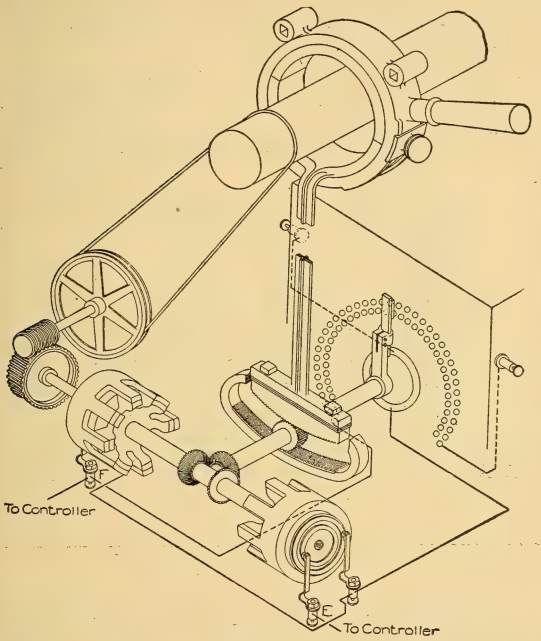


FIGURE 46.

cuit and 1/8 in. at full load; at the same time the rheostat arm is moved over the contacts to cut resistance in or out of the shunt around the field circuit.

The current for the magnetic clutches is regulated by the controller.

The controller consists principally of two magnets which are energized by the main current and act when the current is too high or too low by sending a small current to one of the clutches.

A careful examination of the controller (see Fig. 47), in connection with Fig. 46, will give a clear idea

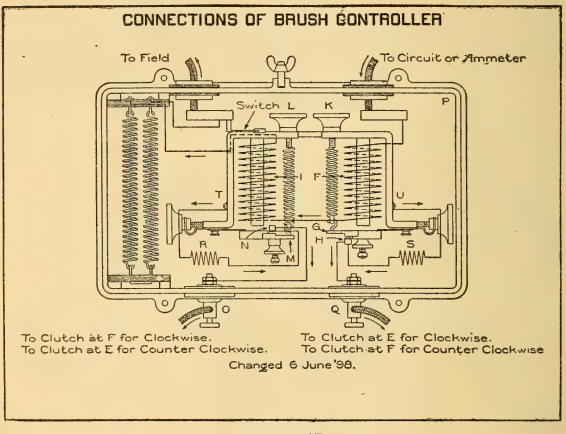


FIGURE 47.

of its regulating action. It is generally advantageous to make the yoke which carries the brushes on the machine and the arm moving the rheostat, rather tight. As the magnetic clutches act with considerable force, it is not necessary to adjust these moving parts so loosely that they will move without considerable pressure on the rocker handle. Less difficulty will then be experienced in adjusting the controller.

For shunt lamps, the controller may be adjusted to permit a variation of .4 ampere above or below normal; for differential lamps, the variation above and below normal should not exceed .2 ampere. The limits given in the following instructions are for differential lamps, and may be extended .2 ampere above or below for shunt lamps.

If the controller is out of adjustment and fails to keep the current normal, do not try to adjust the tensions of both armatures at the same time. For example, suppose the current is too high, either one of the two spools may be out of adjustment. The left-hand spool I may not take hold quickly enough, or the spool F may take hold too quickly. To make the adjustment, screw up the adjusting button K on the right hand spool, increasing the tension. This will have a tendency to let the current fall much lower before the armature comes in contact with H, to cause the current to increase. By simply tapping the armature G quickly with a pencil or piece of wood, forcing it down to its contact, and at the same time watching the ammeter, the current may be brought up to 6.8 amperes if 6.6 amperes is normal, or to 9.8 if 9.6 amperes is normal. With the current at 6.8 amperes, which is .2 ampere high, the adjusting button L should be turned to increase the tension on this spring until the armature M comes in contact with contact N, which will force current down through O. The clutch which pulls the brushes forward and rocks the rheostat back for less current will thus be energized. Repeat this adjustment two or three times, but do not touch the adjusting button K; adjust L until it is just right.

At the side of the armature M a little wedge is screwed in by means of an adjusting button, and

increases or decreases the leverage on this armature. See that this wedge is fairly well in between the core or frame of the spool and the spring of the armature. The armature M may have to be taken out and the spring slightly bent. It is advisable to have the screw which passes through the adjuster button L about half way in, to allow an equal distance up and down for adjusting this lighter spring after the wedge shaped piece is in the right position to give the necessary tension on the spring which is fastened to the armature M.

In the right-hand corner P, a small bent piece of wire is placed for tightening up the screw which fastens the spring to the frame of the spool. As the contact made by the spring and the frame of the spool held together by a screw and button is a part of the magnetic circuit, it will be almost impossible to get this spring back to exactly the same tension after once removing it. Therefore, the adjusting buttons of the controller must be turned slightly in order to bring it back to its proper adjustment. This, however, is an after consideration, and care should be taken to have the screw which holds the spring and frame together always tight.

Having adjusted the spool I so that the current will not rise above 6.8 amperes (or 9.8 amperes), move the armature M up to contact N with a pencil or piece of wood, causing the current to be reduced to about 6.2 (or 9.2). After the current settles at this point, decrease the tension on the spring which is fastened to armature G, allowing this armature to fall down to contact H. Current will then flow through Q, which will rock the brushes back and also move the rheostat arm for more current. As the spool I has been adjusted for 6.8 (or

9.8) amperes, the current cannot rise above that amount no matter how the spool F is adjusted.

With very little practice in moving the armature of one spool with a pencil, the other can be adjusted much more readily than if an attempt is made to adjust the screws K and L at the same time.

The two small shunt coils, R and S, are connected around the two contacts simply to decrease the spark between the silver and platinum contacts. If they should become short circuited in any way, so that their resistances become diminished, sufficient current may pass through either of them to operate the regulator. If unable to locate the trouble disconnect these coils at points T and U, when a thorough examination can be made. M and G need not move more than just enough to open the contact; $\frac{1}{32}$ in. is ample.

In starting the machine, the lower switch, which short circuits the field, should be opened last.

The switch in the left-hand corner of the controller, figure 47 cuts out the two resistance wires which are used to force the current through wires O and Q to the clutches. Open this switch, which leaves the automatic device of the controller in circuit, so that it will move the brush rocker. Unclamp the brush rocker from the rheostat arm rocker. Move the brushes by hand to give the proper spark, allowing the rheostat arm, however, to be moved by the controller. After the switches are opened, the rheostat arm will go clear around to a full load position, and then, as the current rises, the controller takes hold and brings the arm back. In the meantime, rock the brushes forward or backward and keep the spark about the proper length, say $\frac{1}{8}$ in., at full load to $\frac{3}{8}$ in., on short circuit. Gradually the rheostat arm will settle, the spark will

become constant, and the machine will give its proper current. Then clamp the rocker and rheostat arm together and let the machine regulate itself.

This method is much better than opening the switches on the machine and allowing the wall controller to take care of the machine from the start. By allowing the controller to start the machine, a trifle longer spark is obtained than by the other method,

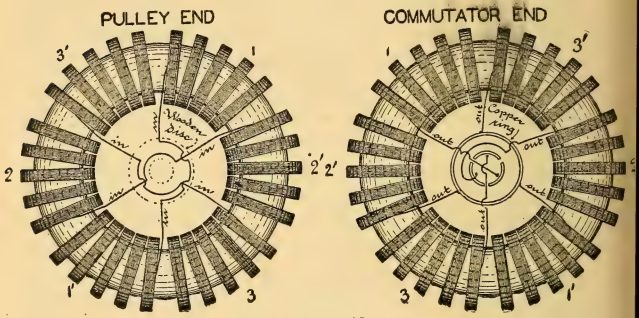


FIGURE 48.

unless the machine is run from the beginning on a very full load.

The machine will require a trifle longer spark on light load, or on bad circuits, than when running at full load. This fact should be borne in mind in wet weather, when trouble with grounds is experienced.

A reliable ammeter should always be connected in the circuit of an arc generator, so that the exact current may be read at a glance. It should be connected into the negative side of the line where the circuit leaves the regulator.

The Thomson-Houston System. The Thomson-Houston dynamo differs from other arc dynamos principally in the nature of its armature winding. This is shown in Fig. 48. One end of each of the three coils is connected to a copper ring common to all. The other end of each coil terminates at one of the three commutator segments. The management and operation of the machine will appear from the following instructions taken from pamphlets furnished by the General Electric Company.

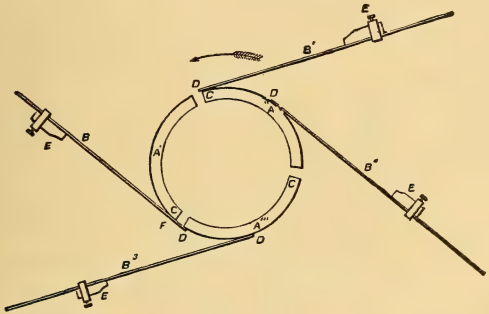


FIGURE 50.

Setting the Cut-out. After the brushes are in position the cut-out must be set. This is done by turning the commutator on the shaft in the direction of rotation (if the commutator is set in position the whole armature must be revolved) until any two segments are just touching the primary brush on that side, as segments A′ and A‴ touch brush B^4 in Fig. 50.

Under these conditions brush B^1 should be at the left-hand edge of upper segment. Then turn commutator until the same two segments are just touching

brush B^2, when the end of brush B^3 should just come to the right-hand edge of the lower segment. If the secondary brush projects beyond the edge of the segment the regulator arm should be bent down; if it does not come to the edge of the segment, the arm should be bent up.

Care must be taken that the regulator armature is down on the stop when the cut-out is being set. These adjustments by bending regulator arm are always made in the factory before testing the machine, and should never be made on machines away from the factory, unless the regulator arm has been bent by accident. If it becomes necessary to make any adjustments they should be made by means of the sliding connection attached to the inner yoke.

Always try the cut-out on both primary brushes. If it does not come the same on both, turn one over. If the brush-holders are correctly set by the gauge, there should be no trouble in getting the cut-out set properly after one or two trials.

To set the commutator in the proper position on a right-hand machine, with a ring armature, find the leading wire of No. 1 coil. It is the custom in the factory to paint this lead red, also to paint a red mark on the center band between two groups of coils, namely, the last half of No. 1 coil and the first half of No. 3 coil. The first half of a coil is that group from which the lead comes. The last half is diametrically opposite the first half and the lead wire belonging to it is connected with the brass ring on the outside of the connection disk on the commutator end.

In Fig. 51 the first halves of the three coils are represented by 1, 2 and 3, and the last halves by 1′, 2′ and 3′.

A narrow piece of tin with sharply pointed ends is bent up over the sides of the middle band at the center of the red mark so that the points are opposite each other.

When the red mark and red lead have been found, turn the armature until the last half of No. 1 coil has wholly disappeared under the left field and until the left-hand edge of the first coil to the right of the red

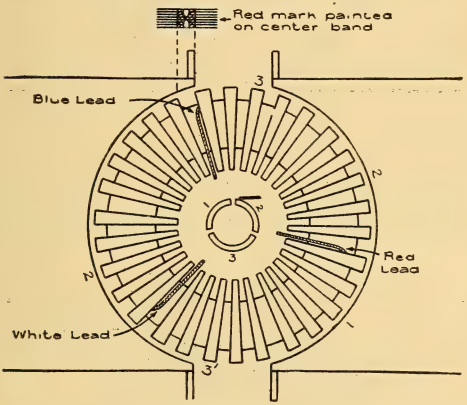


FIGURE 51.

mark (No. 3 in Fig. 51) is just in line with the edge of the left field. The red lead will then be in position shown in Fig 51, and the armature is in proper position to set the commutator.

In the case of the right-hand drum armature the leading wire of the first coil should be found. This lead may be recognized from the fact that it is more heavily insulated than the rest, and is found in the center of

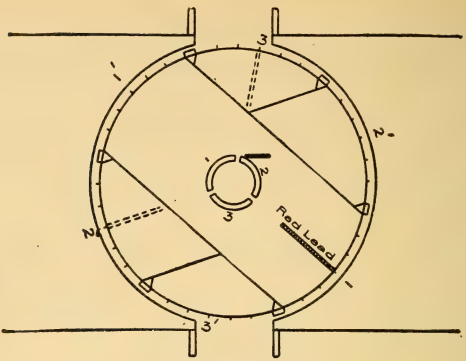


FIGURE 52.

the outer coil, on the commutator end. With this wire turned underneath, rotate the armature forward, or counter-clockwise, until the pegs on the right-hand

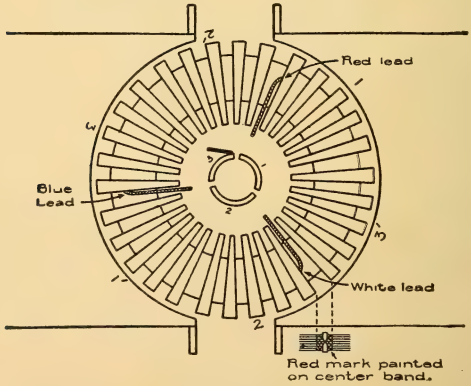


FIGURE 53.

side of this coil just disappear under the left field. (See Fig. 52.)

The position of the red lead and the red mark on the band are the same on all armatures, but their positions in the fields of the machines called left-hand (clockwise rotation), should be as shown in Fig. 53 and 54 when setting the commutator.

When the armature of a right-hand machine is in position, the commutator is turned on the shaft until

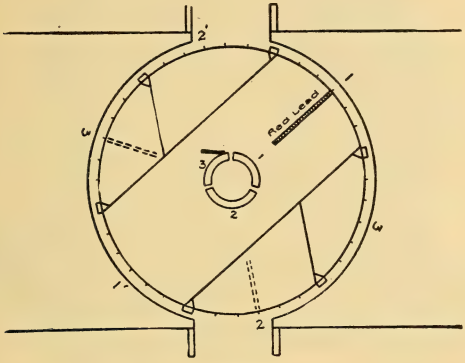


FIGURE 54.

segment No. 1 is in the same relative position as the last half of No. 1 coil; segment No. 2 should correspond with the last half of No. 2 coil, and segment No. 3 with the last half of No. 3 coil, as shown on Figs. 51 and 52.

For left-hand machines, see Figs. 53 and 54.

The distance from the tip of the brush, which is on top, to the left-hand edge of No. 2 segment on a right-hand machine, or to the right-hand edge of No. 3 seg-

ment in a left-hand machine is called the lead, and should be made to correspond with the following table.

TABLE OF LEADS

DRUM ARMATURES.			RING ARMATURES.		
C^{12}	$\frac{1}{4}$ inch	positive	K^{12}	$\frac{3}{16}$ inch	positive
C^{2}	$\frac{3}{8}$ "	"	K^{2}	$\frac{1}{8}$ "	"
E^{12}	$\frac{7}{16}$ "	"	M^{12}	$\frac{1}{4}$ "	negative
E^{2}	$\frac{1}{2}$ "	"	M^{2}	$\frac{1}{2}$ "	"
H^{12}	$\frac{1}{4}$ "	"	LD^{12}	$\frac{1}{4}$ "	positive
H^{2}	$\frac{1}{4}$ "	"	LD^{2}	$\frac{1}{8}$ "	"
			MD^{12}	$\frac{13}{32}$ "	"
			MD^{2}	$\frac{13}{32}$ "	"

Place the screws in the binding posts at the lower ends of the sliding connections, and put on the dash pot connections between the brushes, with the heads of the connecting screws outward. In every case the barrel part of the dash pot is connected to the top brush-holder, and plunger part to the bottom brush-holder.

See that the field and regulator wires are connected and that all connections are securely made.

When all connections have been made, make a careful examination of screws, joints and all moving parts. They must be free from stickiness and not bind in any position.

To determine when the machine is under full load, notice the position of the regulator armature, which should be within $\frac{1}{8}$ in. of the stop. At full load the normal length of the spark on the commutator should be about $\frac{3}{16}$ in. If it is less than this, shut down the machine and move the commutator forward or in the direction of rotation until the spark is of the desired length. If the spark is too long, move the commutator back the proper amount.

A general view of the complete dynamo is given in

Fig. 55, and will help explain the regulator used with this system.

The regulator is fastened to the frame of the machine by two short bolts. On the right-hand machine its position is on the left-hand side, as shown in Fig. 55. On the left-hand machine, *i.e.*, one which runs clockwise, its position is on the opposite side. Before fill-

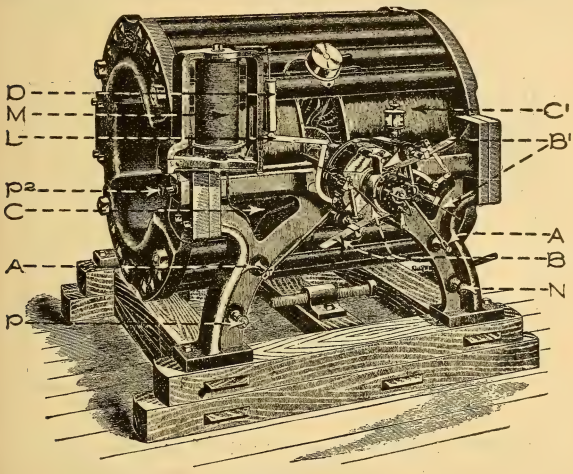


FIGURE 55.

ing the dash pot D with glycerine, see that the regulator lever and its connections, brush yokes, etc., are free in every joint, and that the lever L can move freely up and down. Then fill the dash pot D with concentrated glycerine. The long wire from the regulator magnet M is connected with the left-hand binding post P of the machine, and the short wire with

the post P^2 on the side of the machine. The inside wire of the field magnet, or that leaving the iron flange, of the left-hand field should be connected into post P^2 also, as shown in Fig. 55. The electric circuit (see Fig. 56) should be complete from post P^1, on the controller magnet, through the lamps to the post N on the machine, through the right-hand field magnet C, to the brushes B^1B^1, through the commutator and armature to the brushes B B, through the left-hand field C,

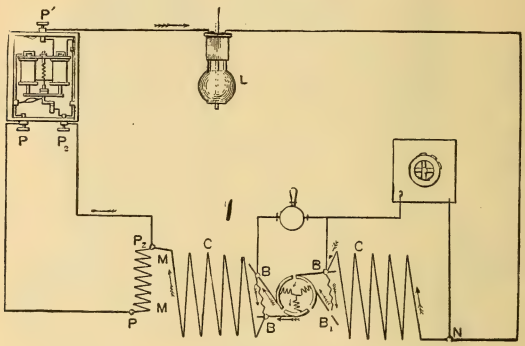


FIGURE 56.

to posts P^2 and P, thence to posts P^2 and P on the controller magnet, through the controller magnet to P^1. The current passes in the direction indicated by the arrows

When an arc machine is to be run frequently at a small fraction of its normal capacity, the use of a light load device is advisable to secure the best results in regulation.

The rheostat for this purpose (see Fig. 57) is connected in shunt with the right field of the generator.

Facing the rheostat with the right binding posts at the bottom, the contact on the right side or No. 1 gives open circuit and throws the rheostat out of use. Point No. 2 gives a resistance of 44 to 46 ohms and Point No. 3 gives a resistance of 20 to 22 ohms.

This rheostat with a 75-light machine allows the following variations: Point 1, 75 to 48 lights; Point 2, 48 to 25 lights; Point 3, 25 lights or less. For use with

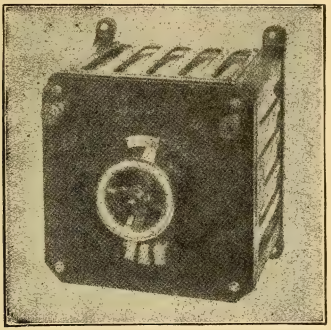


FIGURE 57.

other sizes of generators, the adjustment of the rheostat must be made to suit the conditions.

When the rheostat is in use, the sparks at the commutator will be somewhat larger than normal, but will not be detrimental.

The controller magnet (see Fig. 58) is to be fastened securely by screws to the wall or some rigid upright support, taking care to have it perfectly plumb. It is connected to the machine in the manner shown in Fig. 55, *i.e.*, the binding post P^2 on the controller magnet is

connected to the binding post P^2 (see Fig. 55) on the end of the machine, and likewise the post P on the controller to the post P on the leg of the machine; the post P^1 forms the positive terminal from which the circuit is run to the lamps and back to N.

Great care should be taken to see that the wires P P

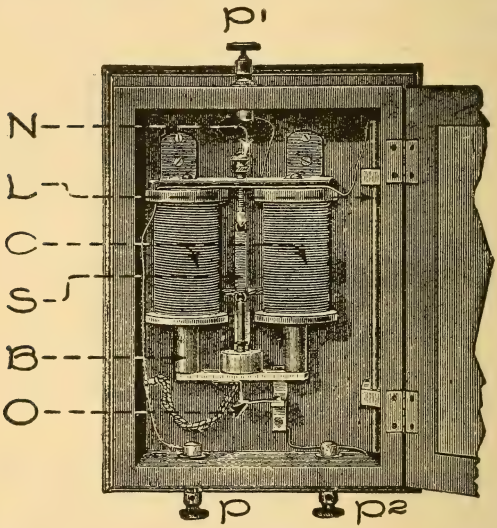


FIGURE 58.

and P^2 P^2 are fastened securely in place; for if connection between P and P should be impaired or broken, the regulator magnet M would be thrown out of action, thus throwing on the full power of the machine, and if the wire P^2 P^2 should become loosened, the full power of the magnet M would be thrown on, and the regu-

lator lever L, rising in consequence, would greatly weaken or put out the lights.

The wires leading from the controller magnet to the machine should have an extra heavy insulation.

Care should be taken in putting up the controller magnet that the following directions are followed:

1. The cores B of the axial magnets C C must hang exactly in the center, and be free to move up and down.

2. The screws fastening the yoke or tie pieces to the two cores must not be loosened.

3. The contacts O must be firmly closed when the cores are not attracted by the coils C C, which is the case, of course, when no current is being generated by the machine, and when the cores are lifted, the contacts must open from $\frac{1}{64}$ in. to $\frac{1}{32}$ in.; a greater opening than $\frac{1}{32}$ in. has the effect of lengthening the time of action of the regulator magnet. This tends to render the current unsteady, and in case of a very weak dash pot or short circuit might cause flashing. Adjustment must be made if necessary by bending the lower contact up or down, taking care that it is kept parallel with the upper contact, so that when they are closed, contact will be made across its whole width. If this adjustment is not properly made there will be destructive sparking on a small portion of the contact surfaces.

4. All connections must be perfectly secure.

5. The check nuts N must be tight.

6. The carbons in the tubes L must be whole. These carbons form a permanent shunt of high resistance around the regulator magnet M, and if broken will cause destructive sparking at contacts O, burning them and seriously interfering with close regulation of the generator. In case a carbon should become broken,

temporary repairs may be made by splicing the broken pieces with a fine copper wire.

To keep the action of the controller perfect the contacts O should be occasionally cleaned by inserting a folded piece of fine emery cloth and drawing it back and forth.

The amount of current generated by each machine

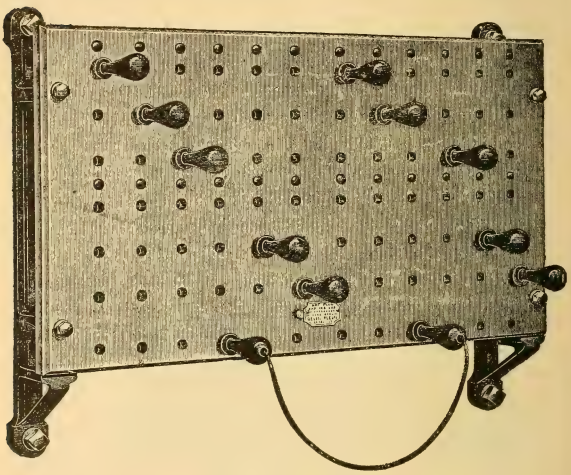


FIGURE 59.

depends upon the adjustment of the spring S. If the tension of this spring is increased the current will be diminished; if the tension is diminished, the current will be increased.

In starting these dynamos when the armature has reached its proper speed, the short circuiting switch on the frame should be opened. This method allows the

generator to take up its load gradually, and is a very important point in the handling of the machine.

Arc Switchboards. Fig. 59 shows a general view of the Thomson-Houston plug switchboard. A rear view of the same board is given in Fig. 60.

In a standard panel the number of horizontal rows of holes equals one more than the number of generators. The vertical holes are always twice the number of generators. The positive leads of the generators are

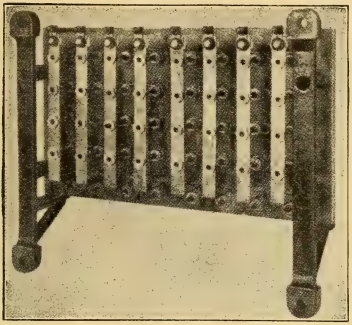


FIGURE 60.

attached to the binding posts on the left-hand ends of the horizontal conductors. The negative leads are connected to the corresponding binding posts at the right-hand end of the board.

The positive line wires are connected to the vertical straps on the left, and the negative wires to the similar straps on the right of the center panel.

If a switchboard plug be inserted in any of the holes of the board, it puts the corresponding generator lead

and the line wire in electrical connection, but as the positive line wires are back of the positive generator leads only, it is not possible to reverse the connection of the line and the generator accidentally, though any other combinations of lines and generators can be made readily and quickly.

The holes of the lower horizontal rows have bushings connected with the vertical straps only. Plugs connected in pairs by flexible cable and inserted in the holes put the corresponding vertical straps in connection as needed, and normally independent lines may be connected when one generator is required to supply several circuits.

Lines and generator leads may be transferred, while running, by the use of these cables, without shutting down machines or extinguishing lamps.

The standard boards are arranged for an equal number of generators and circuits, but special boards for any ratio of circuits to generators can be built.

As it is sometimes convenient, even in small plants, to interchange lines and generators without shutting down machines, a special transfer cable with plugs has been devised. This serves the same purpose as the regular transfer cable, but the plugs may be used in any of the holes of the switchboard, as they are insulated, except at the tip, and when inserted connect with the line strips only.

The transfer of circuits from one generator to another gives trouble to dynamo tenders who are not familiar with the operation of these plug switchboards. Fig. 61 illustrates the successive steps for transferring the lamps of two independent circuits from two generators to one without extinguishing the lamps on either circuit.

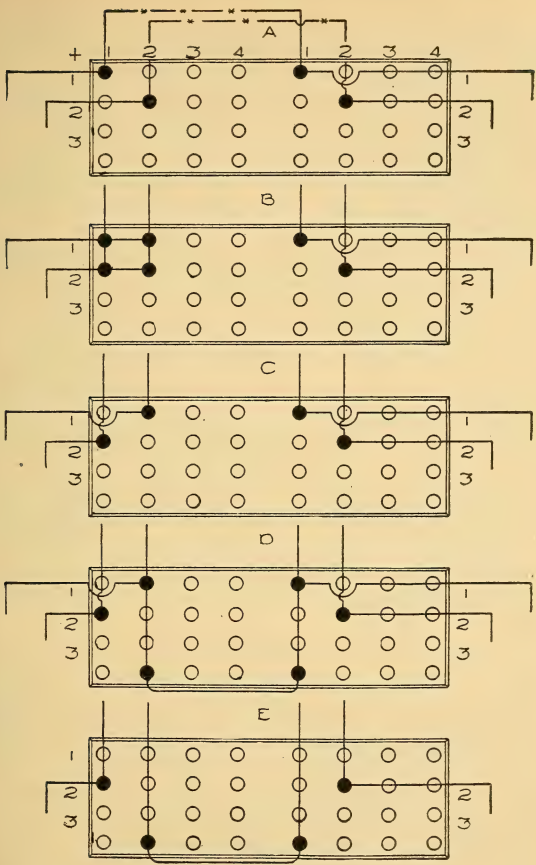


FIGURE 61.

This process is a very simple example of switchboard manipulation, but illustrates the method used for all combinations.

The location of plugs is shown by the black circles, which indicate that the corresponding bars of the horizontal and vertical rows are connected.

Circuit No. 1 and No. 2, running independently from generators No. 1 and No. 2 respectively, are to be transferred to run in series on generator No. 2.

In A, Fig. 61, are two circuits running independently; in B the positive sides of both generators and circuits are connected by the insertion of additional plugs.

At C both generators and circuits are in series.

Next insert plugs and cables as shown in D. Then withdraw plugs on row corresponding to generator No. 1, and the circuits No. 1 and No. 2 are in series on machine No. 2, and machine No. 1 is disconnected as at E.

Similar transfers can be made between any two circuits or machines, and by a continuation of the process additional circuits can be thrown in the same machine. The transfer of the two circuits to independent generators is accomplished by reversing the process illustrated.

Fig. 62 shows the wiring and connections of the Western Electric Co.'s series arc switchboard. At the top of the board are mounted six ammeters, one being connected in the circuit of each machine. On the lower part of the board are a number of holes, under which, on the back of the board, are mounted spring jacks to which the circuit and machine terminals are connected. For making connections between dynamos and circuits, flexible cables terminating at each end in a plug, are used; these are commonly called "jump-

ers." The board shown has a capacity of six machines and nine circuits, and with the connections as shown machine 1 is furnishing current to circuit 1, machine 2 is furnishing current to circuits 2 and 3, and machine 4 is furnishing current to circuits 4, 5 and 7. In connecting together arc dynamos and circuits the positive of the machine (or that terminal from which the current is flowing) is connected to the positive of the cir-

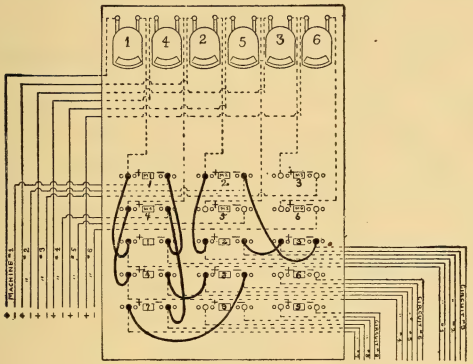


FIGURE 62.

cuit (the terminal into which the current is flowing). Likewise the negative of the machine is connected to the negative of the circuit. Where more than one circuit is to be operated from one dynamo, the – of the first circuit is connected to the + of the second. At each side of the name plate (at 3, for instance) there are three holes. The large hole is used for the permanent connection, while the smaller holes are used for transferring circuits, without shutting down the

dynamo. Smaller cables and plugs are used for transferring. If it is desired to cut off circuit 5 from machine 4, a plug is inserted in one of the small holes at the right of 4, the other plug being inserted in one of the holes at the left of 7. Circuit 5 would now be short circuited, and the plug in the + of 5 can now be transferred to the permanent connection in the + of 7, and the cords running to 5 removed. If it is desired to cut in a circuit, say circuit 6 onto machine 2, insert a cord between the − of circuit 2 and the + of 6 and another between the − of 6 and the + of 3. Now pull the plug on the cord connecting − of 2 and the + of 3 and insert the permanent connections. In cutting in circuits, if they contain a great number of lights, a long arc may be drawn when the plug between 2 and 3 is pulled, and it is sometimes advisable to shut down the machine when making a change of this kind.

CHAPTER V

MOTORS.—ALTERNATING CURRENT MOTORS.

Motors. Any dynamo may be used as a motor and consequently we have as many types of motors as there are types of dynamos. The pull of a motor depends upon the repulsion and attraction between the lines of force, or magnetism of the wire and core of the armature and that of the fields. We have seen that in a dynamo, as we force a wire through a magnetic field, current is generated. The more current there is generated or flowing in such a wire, the greater will be the expenditure of power necessary to force such a wire through a magnetic field; in other words, the currents flowing in the wires of a dynamo armature, always tend to drive the armature in a direction opposite to that in which it is being driven.

If, then, instead of revolving a dynamo armature by mechanical means, we connect it to a source of electricity and allow a current to flow through it we must obtain motion, and the direction of this motion will depend upon the direction in which the current flows, so long as this current does not alter the magnetism of the fields.

We have already seen that the electric motor is built exactly like a dynamo; consequently, as its armature revolves it not only does useful work, such as turning whatever machinery it is belted to, but it also generates an electromotive force. For instance, if a motor, running at full speed and receiving current from a

dynamo (Fig. 63), were suddenly disconnected by opening the main switch, it would at once begin acting as a generator and sending out current. This can be easily seen with any motor equipped with a starting box, such as shown; for the current from the motor will continue to energize the fields and the little magnet M so as to hold the arm of the starting box until the motor has nearly come to rest. If it were not for the current generated by the motor, this arm would fly back the instant the switch is opened.

The electromotive force set up by a motor always opposes that of the dynamo driving it; that is, the current which the motor tends to send out would flow in the opposite direction to that which is driving it.

This may be compared, and is somewhat similar, to the back pressure of the water which a pump is forcing into a tank. If the check valves were removed and the steam pressure shut off, the water would tend to force the pump backward.

This electromotive force is called the counter electromotive force of the motor. The counter electromotive force of the motor varies with the speed of the motor and also limits the speed of the motor, for it is obviously impossible that a motor should develop higher counter E. M. F. than the E. M. F. of the dynamo driving it.

This highest possible speed of a motor is, then, that speed at which its counter E. M. F. becomes equal to the E. M. F. of the dynamo supplying the current, and this is the speed which would be obtained were the motor doing no work and running without friction. This condition is impossible in practice, and the counter E. M. F. of the motor is always less than the E. M. F. of the dynamo. In order to speed up a

motor we must arrange it so that it must run faster in order to develop an E. M. F. equal to that of the dynamo; we can do this by lessening the number of turns of wire on the armature, or by lessening the magnetism of the fields. In doing so, however, we also lessen the capacity of the motor for performing work.

The power that can be obtained from an electric motor depends upon two things: the current flowing in its armature coils and the strength of magnetism developed in the fields.

Assuming the fields as remaining constant, the power of the motor must then vary as the current flowing through it. Suppose we have a motor being driven by an E. M. F. of 110 volts and it is doing no work; it will be running at full speed and its counter E. M. F. will therefore also be very near 110 volts. If now a load be thrown on this motor, it must get more current in order to develop the necessary power to carry the load.

Throwing on the load will decrease the speed of this motor, and consequently its counter E. M. F. will fall, say to 100 volts. The E. M. F. of the dynamo being 110 and the counter E. M. F of the motor 100, there will be considerable current forced through the armature of the motor, so that it can now handle the load.

The current in the armature at all times will equal $\frac{E - E'}{R}$, where E is the electromotive force of the dynamo, E′ the counter electromotive force of motor, and R the resistance of the motor armature. In order that a motor should keep a nearly uniform speed, for varying loads, the resistance of its armature should be very low, for then a slight drop in counter E. M. F.

will allow considerable current to flow through the armature. The above applies particularly to the shunt motor shown in Fig. 63. In this diagram C is a double pole fuse block, S the main controlling switch, R the starting box, or rheostat, M the magnet, which holds the arm of the starting box in place when it is brought

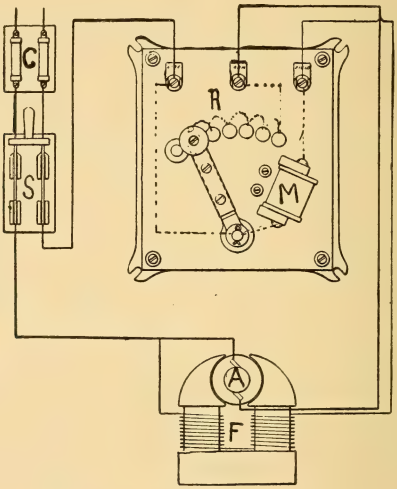


FIGURE 63.

over against it, F the fields, and A the armature of the motor.

The current enters, say at the right hand fuse, and passes to the starting box and along the fine wires shown in dotted lines through the fields of the motor and coil M to the other fuse. The fields of the motor and the little magnet M are now charged, but as yet

there is no current passing through the armature and no motion. We now slowly move the arm on the starting box to the right; this admits a little current, limited by the resistance in the starting box, to the motor armature and it begins to revolve, and as we continue to move the arm to the right, the armature gains in speed because we admit more current to it by cutting out more and more resistance. When the armature attains full speed, the arm comes in contact with the little magnet M, and is held there by magnetism. The whole object of the starting box is to check the inrush of current, while the armature is developing its counter E. M. F. or back pressure.

When the armature has attained its normal speed, the starting box is no longer in use. If for any reason the current ceases to flow, the little magnet M loses its magnetism and releases the arm, which (actuated by a spring) flies back and opens the circuit so that, should the current suddenly come on again, the sudden inrush will not damage the armature.

In Fig. 64 are shown the connections of a series wound motor with an automatic release spool on the starting box of a sufficiently high resistance so it can be connected directly across the circuit. This becomes necessary since the field windings are in series with the armature.

The speed of a series motor may be decreased by connecting a resistance in series with the motor and may be increased in speed by cutting out some of the field windings. In electric railway work where two motors are used on one car, they are usually connected in series with each other in starting up and then in parallel with each other while running at full or nearly full speed. The series motor is well adapted to such

work as electric railway work, or for cranes and so forth, because it will automatically regulate its speed to the load to be moved, exerting a powerful torque at a low speed while pulling a heavy load. Such a motor, however, requires constant attendance when the

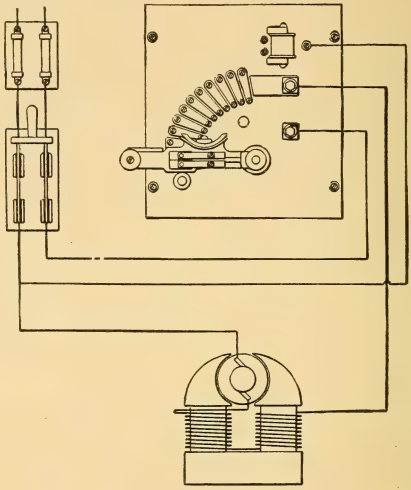


FIGURE 64.

load becomes light, as it will tend to "run away" unless its speed is checked.

In Fig. 65 we have a diagram of a compound wound motor connected with a type of starting box that cuts out the armature when current has been cut off the lines supplying the motor, as before explained. In addition to this there is another electro magnet which is traversed by the main current on its path to the armature. Should the motor be overloaded by some

means, the current flowing to the armature would exceed the normal flow. The magnetism thus produced would overcome the tension of a spring on the armature of the so-called "overload magnet" and cause it to short circuit the magnet which holds the resistance lever and allow it to fly back and open the arma-

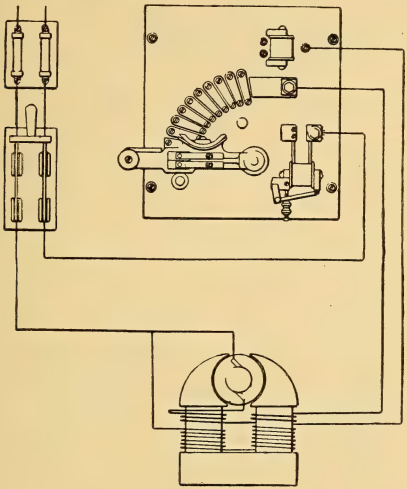


FIGURE 65.

ture circuit. By so doing the liability of burning out the armature due to overload is reduced to a minimum.

The compound motor may be made to run at a very constant speed, if the current in the series winding of the fields is arranged to act in opposition to that of the shunt winding. In such a case an increase in the load of a motor will weaken the fields and allow more current to flow through the armature without decreasing

the speed of the armature, as would be necessary in a shunt motor. Such motors, however, are not very often used, since an overload would weaken the fields too much and cause trouble.

If the current in the series field acts in the same

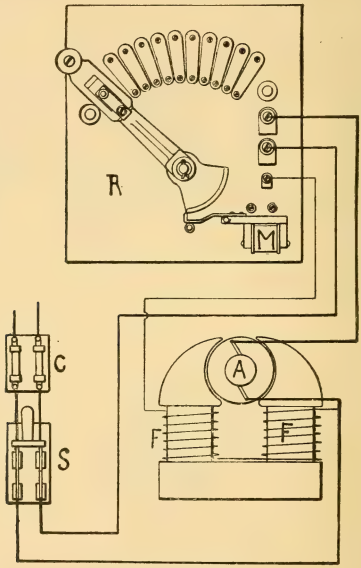


FIGURE 66.

direction as that of the shunt fields, the motor will slow up some when a heavy load comes on, but will take care of the load without much trouble. Fig. 66 shows a starting box arranged as a speed controller. It differs from other starting boxes only in so far that the resistance wire is much larger and that the little

magnet will hold the arm at any place we desire, so that if we leave the arm at any intermediate point the motor will run at reduced speed. This sort of speed regulation can be used only where the load on the motor is quite constant. If the load varies, the speed will vary. Another and a better way of varying the speed of motors consists in cutting a variable resistance into the field circuit, as more resistance is cut into the circuit the fields become weaker and the motor speeds up. If possible, motors should be so designed that they can operate at their normal speed, and they will then cause little trouble.

Motors have much the same faults as dynamos, but they make themselves manifest in a different way. An open field circuit will prevent the motor from starting and will cause the melting of fuses or burning out of an armature. The direction of rotation can be altered by reversing the current through either the armature or the fields. If the current is reversed through both, the motor will continue to run in the same direction. A short circuit in the fields, if it cuts out only a part of the wiring, will cause the motor to run faster and very likely spark badly. If the brushes are not set exactly opposite each other, there will also be bad sparking. If they are not at the neutral point, the motor will spark badly; brushes should always be set at the point of least sparking. If it becomes necessary to open the field circuit, it should be done slowly, letting the arc gradually die out; a quick break of a circuit in connection with any dynamo or motor is not advisable, as it is very likely to break down the insulation of the machine.

The ordinary starting box for motors is wound with comparatively fine wire and will get very hot if left in

circuit long. The movement of the arm from the first to the last point should not occupy more than thirty seconds, and if the armature does not begin to move at the first point the arm should be thrown back and the trouble located.

Alternating Current Motors. By a proper combination of two phase or three phase currents it is possible to produce a revolving magnetic pole. By placing inside of the apparatus which produces this revolving magnetic pole a suitable short circuited armature, this armature will be dragged around by the revolving pole in much the same way that a short circuited armature in a direct current machine would be dragged around if the fields were revolved. Such a machine is called an induction motor. The armature will revolve without any current entering it from the external circuit. This does away with commutators, collector rings, brushes, brush-holders, and in fact many of the parts which are so necessary in direct current machines. The rapidity of the alternations in the external circuit determines the speed of the motor.

Some alternating current motors are known as "synchronous" motors. What is meant by synchronous is, occuring at the same time, or in unison. As an example, suppose two clocks are ticking just alike so that the pendulums start and stop at the same time; we would hear but one tick. These two clocks would then be in synchronism. If an alternating current generator has 32 field coils and revolves at the rate of 60 R. P. M., then a synchronous motor with only 4 field coils would revolve at the rate of 480 R. P. M. This motor would operate in synchrony with the generator and yet would make 480 R. P. M. while the generator made 60 R. P. M.

CHAPTER VI

Fuses and Circuit Breakers. Fuses are metal wires or strips, generally made of an alloy of lead and antimony, the amount of each metal used being so proportioned that the wire will melt at a certain temperature. This metal is very similar to that used in the fusible plugs in boilers. These fuse strips or fuse wires are placed in the various circuits in such a manner that the current must first flow through the fuse before entering the lights, motors or other electrical apparatus. If a short circuit should occur, there would be an excessive amount of current flow through the fuse and the temperature of the metal would be raised to the point where it would melt and open the circuit. This would cut off the current and save the electrical apparatus from being damaged by the excessive current. Fuses are placed in the various circuits in accordance with the rules and regulations of the National Board of Fire Underwriters. These rules require a fuse to be placed in the circuit of every piece of electrical apparatus liable to be short circuited, and also at points where small wires are tapped onto larger ones, unless the main fuse in the larger wire is small enough to protect the smallest wire in the circuit. The ordinary commercial fuse wire is not intended to melt until the current has reached a strength of about twice the number of amperes marked on the fuse. A few good points to remember in regard to fuses are as follows: Unless the fuses are of the new enclosed type (fuses entirely encased in small tubes) or unless they are under the eye of a constant attendant, they should be enclosed in fireproof boxes. This should be done to minimize the chance of the red hot metal from a

melted fuse dropping into some inflammable material. It is a very good plan to enclose all fuses. Fuses placed in a hot room will blow at a lower increase in current than those in a cool room. Always use copper tipped fuses, both for the purpose of getting a good contact at the binding screw and for the reason that the blowing point of a fuse wire depends on the length of the wire. Two pieces of fuse wire of the same diameter, but of different lengths, will not blow with the same current because the cooling effect of the terminals is greater with the shorter fuse.

In the larger size fuse strips see that the contacts between the fuse terminal and the binding post are free from dirt and that there is plenty of contact between them, otherwise the poor contact will heat up the terminal and the fuse strip and cause it to blow at a much lower current strength than that for which it is marked. Oil between the contacts will cause heating and the same result.

From the fact that when a fuse strip has blown the current will be off the circuits which are protected by the strip until the fuse has been replaced, and this takes some time, another device known as the circuit breaker has come into general use. The circuit breaker is simply a knife switch equipped with a spring which tends to open it, and is held in place by a small catch. The current passing through the switch also passes through the winding of a small solenoid on the inside of which is an iron core. When the current passing through the solenoid exceeds a certain amount, the iron core is drawn up into the solenoid, and in doing so strikes the catch holding the switch and releases it, thus opening the switch and cutting off the current. Circuit breakers are nearly always installed in the cir-

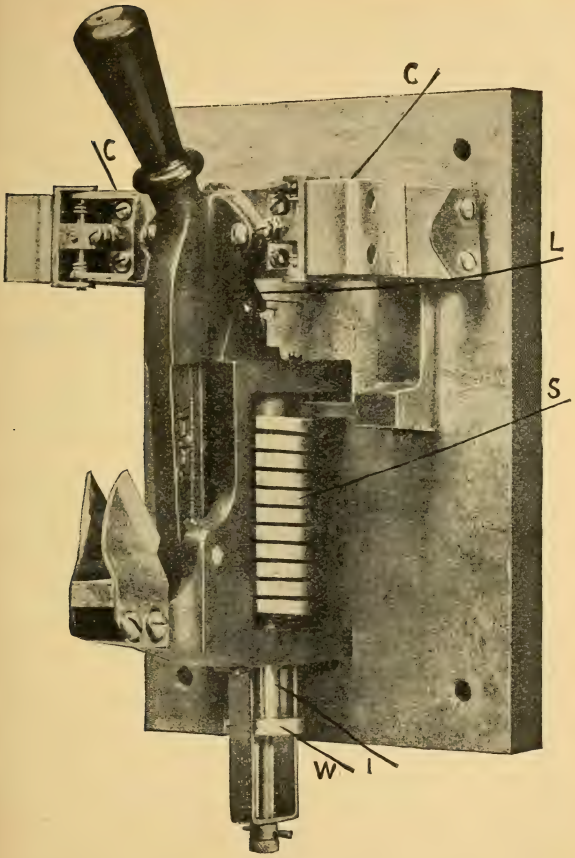


FIGURE 67.

cuits of generators, although fuses are also used. The fuse is rated higher than the circuit breaker, so that the circuit breaker will operate first and the fuse only operates when the circuit breaker fails to work. Circuit breakers are also used to a large extent in protecting large motors, and the small overload devices used on motor starting boxes are simply circuit breakers. Fig. 67 shows a view of an I-T-E circuit breaker. S is the solenoid and I the moveable iron core. This core is adjustable, by means of the washer W, so that it will operate at whatever current desired. L is the catch which holds the switch. Carbon contact pieces, C C, are so arranged that the current is broken on them, thus taking the arc off the blades. In Fig. 68 a diagram of a circuit breaker used for the protection of a motor is shown. In this case the circuit breaker is double pole; while the one shown in the preceding figure is single pole.

For small work, such as tap lines and small motors, the circuit breaker is too expensive to warrant its use, but for capacities of 50 amperes and over it is advisible to use the circuit breaker. Circuit breakers are also designed and used to prevent the liability of short circuits between generators connected in parallel, due to the reversal of polarity of one of the dynamos. In other words, should one of the dynamos become reversed in polarity while working in parallel with other machines, the polarity circuit breaker would open the machine-switch and cut it out. Circuit breakers of this description are also used in charging storage batteries. Sometimes circuit breakers are referred to as overload switches. The mechanical operation of these instruments can be readily understood when examined, as they are all of a very simple mechanical construction.

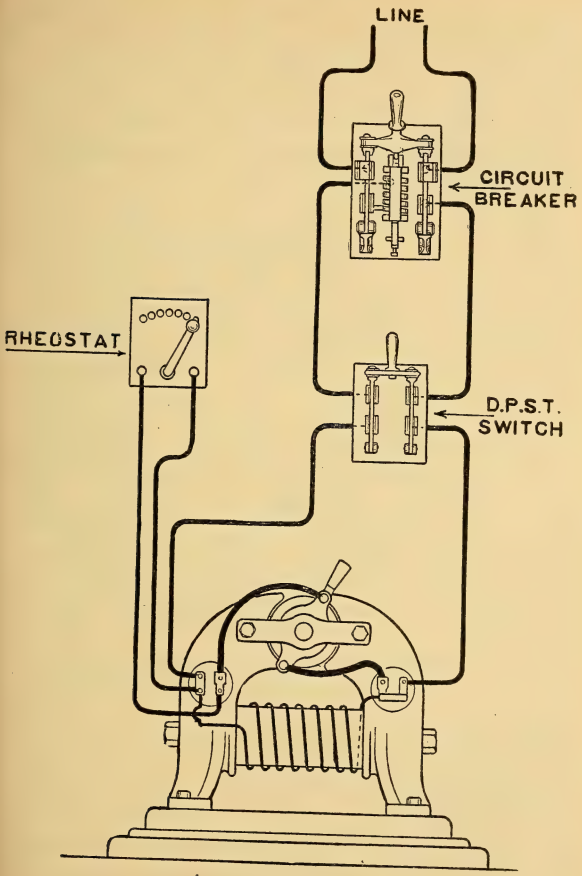


FIGURE 68

CHAPTER VII

ALTERNATING CURRENT DYNAMOS

Alternating current dynamos are operated upon the same general principle of magnetic induction as that involved in continuous current dynamos. The mechanical construction, however, differs considerably in the two types of machines. The current produced in the two types is identical, but in the direct current machine this current is rectified by means of a commutator; that is, the current constantly flows out one wire and back in the other wire, never changing in direction in the external circuit. In the alternating current dynamo the current is sent to the line exactly as it is generated in the armature, flowing out one wire and back on the other and then reversing and flowing out on the wire on which it has just flowed in, and back on the wire on which it had formerly flowed out. An illustration which will more fully explain this action can be found by supposing the two ends of the cylinder of a piston pump were connected by means of a pipe and then, having done away with all the valve movements, the pumps were started. At the beginning of the stroke, water would be forced out one side of the cylinder around the pipe into the other side of the cylinder, and after the piston had reached the end of the stroke and started back, the water would then take a return course back to where it had started. In this case the pump could be likened to the dynamo and the pipe to the wires, and the current to the water flowing back and forth. The form and winding of

alternating current dynamos varies considerably, but they generally follow the plan shown in Fig. 69. In the figure the pole pieces are alternately north (N) and south (S), while the armature is wound with the same number of poles, with the winding so arranged that the poles alternate. The fields are excited by direct current passing over the field coil windings. This

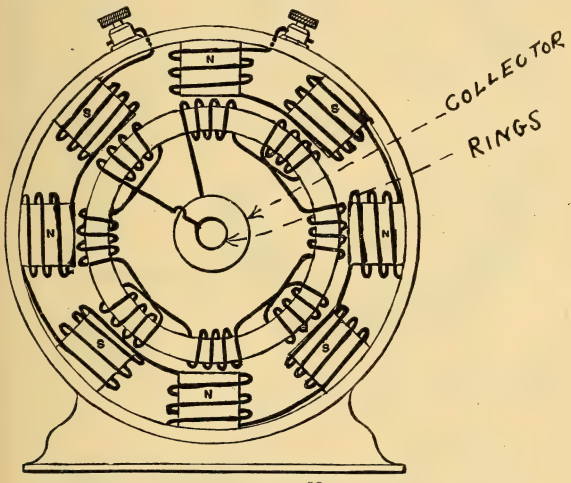


FIGURE 69.

direct current is usually obtained from another source aside from the current generated in the armature of the alternating current dynamo. A separate dynamo, called an exciter, is employed for supplying the current to the fields. There are some types of so called "composite wound alternating current dynamos" in which a part of the current from the alternator arma-

ture is rectified or commutated by means of a commutator mounted on the same shaft with the armature,

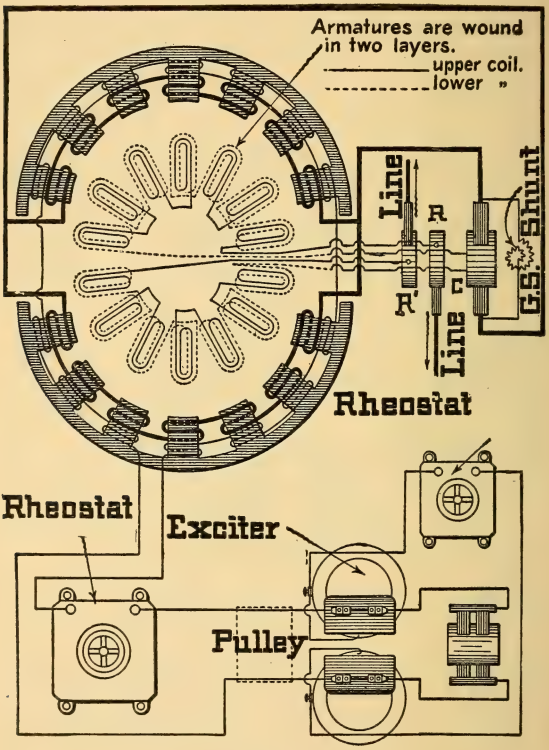


FIGURE 70.

and this commutated current passed around the field coils in a manner similar to the direct current com-

pound wound dynamo. In Fig. 70 we have a diagram of connections of a composite wound machine made by the General Electric Company. It will be noticed that in connection with this dynamo we still employ a separate direct current exciting machine. The object of this composite winding is the same as with the compound wound direct current dynamo, namely, regulation under variable loads without the necessity of changing the strength of the field exciting current from the exciter dynamo. The winding of the alternate current armature consists of the same number of armature coils as there are pole pieces in the fields of the machine. The outer end of the first armature coil is left free to be connected to one of the collector rings, while the other end of the coil is connected to the inner end of the second coil; the outer end of the second coil is connected to the outer end of the third coil, and so on through the entire armature. In this class of winding you can readily see that while the coils connected from the underside or inner ends are under the influence of one polarity of field magnetism, the armature coils connected from the outer side are under an opposite magnetic influence. The purpose of forming the armature circuit in this manner may be fully understood when it is remembered that the magnetism from the north pole of a magnet will induce a flow of electricity in a coil of wire in a given direction, while the magnetism of the south pole will induce a flow of current in an opposite direction. Now, for the reasons just explained, the current in all of the coils of the armature will flow in the one direction, but as the armature is rotated sufficiently to move the coils from the influence of one pole to the influence of the opposite pole which is next to it, the action of all the magnetic poles

of the field reverse all the inductions in the armature coils and cause the current to flow in an opposite direction. The number of reversals occurring during a revolution is determined by the number of poles that the armature coils pass during one revolution. One of these armature coils we will assume to be under a north magnetic influence and in its rotation it passes through a south magnetic influence, thence into a north magnetic influence again. The current has now alternated or reversed its direction of flow twice and has passed through what is called one cycle. If the current were making 120 alternations or passing through 60 cycles in one second, it would be known as making 60 cycles or alternating at the rate 7,200 alternations per minute. These are the general terms used in designating alternating currents.

By tracing out the circuits in Fig. 70, it will be seen that, assuming the current to be flowing into the collector ring R, it will pass through the upper half of the armature winding and out to the commutator C, where a part of it will be commutated (or changed into direct current), then flowing back around the lower half of the armature windings and out to the other collector ring R'. On the commutator C the upper line coming from the armature is connected to each alternate segment, while the lower line is connected to the remaining segments. The amount of current which is thus rectified and flows around the two halves of the field winding, which are connected in parallel, is regulated by means of the German silver shunt. The fields are also energized by the current generated in the small dynamo known as the exciter.

In Fig. 71 is shown an alternating current dynamo with its separate exciter The two collector rings are

shown immediately at the right of the armature, while at the right of the collector rings is shown the commutator from which the current for the composite winding of the fields is taken. The current generated by the alternator is regulated in the same way as with direct current dynamos; that is, by varying the current sent around the field windings. This is accomplished by the use of a resistance box in series with the exciting

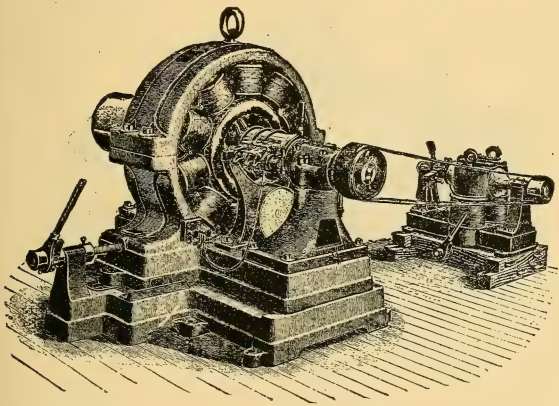


FIGURE 71.

current or by means of a resistance box connected in the fields of the exciting dynamo. This latter regulation is of course the more economical, as there would be considerable energy wasted were a resistance used in the main exciting circuit. Alternating currents are generally used where currents are to be transmitted long distances, as for instance, where power is derived from a water fall situated some distance from the

point of use Its adaptability for such work is apparent, because it can be generated at high voltages and transformed down to any voltage desired. It requires less copper to transmit it, due to the higher voltages employed. By the aid of transformers it can either be stepped up to a higher pressure or stepped down to as low a pressure or voltage as desired. Another great advantage is that, after it has been transmitted a considerable number of miles, by the aid

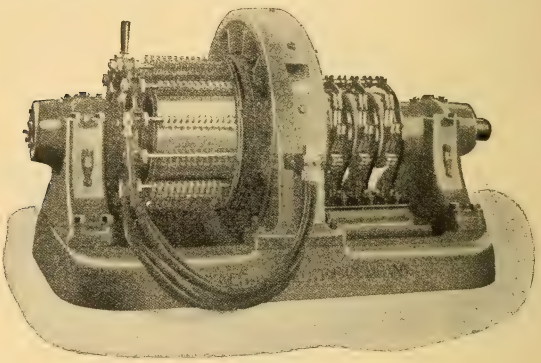


FIGURE 72.

of a rotary converter it can be converted into direct current.

Rotary transformers which transform the alternating current to a direct current are simply alternating current motors connected to direct current dynamos. Sometimes these machines are mounted on the same shaft; sometimes they are belted together, and in some cases the same windings are used for both machines; a commutator being mounted at one side of the armature

from which direct current is taken while the alternating current is taken into the armature on a pair of collector rings on the opposite end of the shaft. In Fig. 72 is shown a view of a rotary transformer where the alternating current is taken in at the right, and direct current taken off at the commutator on the left.

By single phase we understand that the current flows out, gradually increasing in strength, then dying away and reversing in direction and again increasing and dying away. This action is shown by the curve in

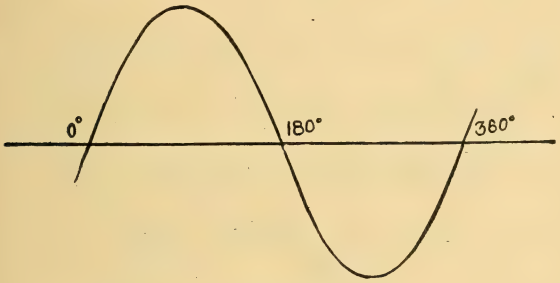


FIGURE 73.

Fig. 73. Although the single phase alternating current system is in advance of the direct current system for electrical power transmission, because permitting electrical power to be transmitted long distances at high potential, which can be readily increased or reduced by means of transformers, the single phase system is limited by the difficulty in obtaining a satisfactory self starting motor; therefore the use of the single phase current has been confined almost entirely to transmitting current for lighting. The development of the polyphase (two phase and three phase) alter-

nating systems possess all the advantages of the single phase system and at the same time permits the use of motors having not only most of the valuable features of the continuous current motors, but also some advan-

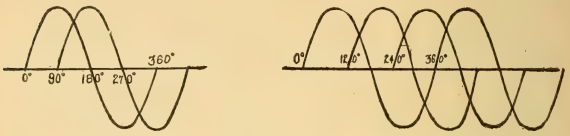


FIGURE 74.

tages over them. In the two phase system two currents displaced 90 degrees from each other and otherwise exactly similar to the single phase currents are used. In the three phase system three currents separated 120 degrees are used. These currents are shown in Fig. 74.

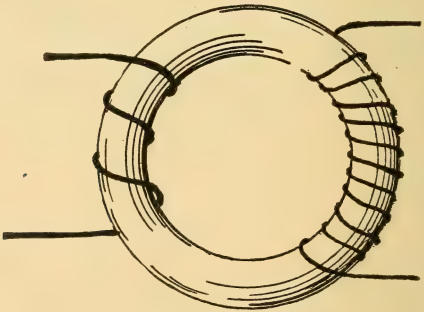


FIGURE 75.

In Fig. 75 is shown the principle upon which the transformer used in alternating current work are operated. Two separate coils of wire are wound on a ring

of laminated iron. One of the coils contains a number of turns of fine wire, while the other contains only a few turns of large wire. When an alternating current is sent around the coils of fine wire, generally called the primary, a current will be induced in the coil of heavy wire, or secondary. The amount of current induced in the larger wire will be relatively greater in amperes and less in potential than that of the fine wire circuit. This ratio is almost entirely dependent upon the relative number of turns existing

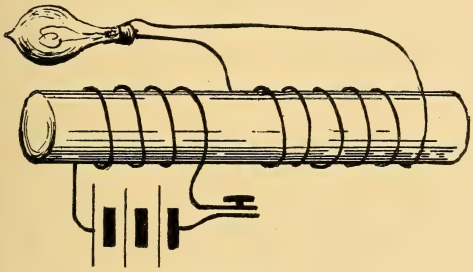


FIGURE 76.

between the large and the small wires. To illustrate, suppose we had a current of 10 amperes at a pressure of 1,000 volts in the primary, and there were ten times as many turns of wire in the primary coil as in the secondary, then we would get a current of 100 amperes at a pressure of 100 volts in the secondary coil. This same relation would hold true whatever the ratio between the number of turns on the two coils might be. In Fig. 76 is shown a core of iron having on one end a primary coil connected to a battery. On the other end of the core is another coil connected to the

ends of which is an incandescent lamp. By making and breaking the battery circuit the lamp may be made to flash up, due to the great voltage induced in the secondary coil. This is a good thing to remember when working with a dynamo or motor. Do not quickly break the shunt field connection, as the increased voltage due to the current induced by the field magnet when the circuit is broken is liable to puncture the insulation and necessitate the re-winding of the field coil.

CHAPTER VIII

METERS

Volt and Ampere Meters. Two of the most important instruments used in electrical work are the voltmeter and amperemeter, the latter generally called ammeter. Classed with these instruments is a meter of an important nature called the wattmeter. We will first become acquainted with the voltmeter, which is an instrument, as its name implies, for measuring the voltage or potential or electromotive force between two wires. The general construction of this instrument is shown in Fig. 77.

In this diagram we show an instrument on the order of the Weston meter. This will serve as a good illustration that the operation of meters is very similar to the operation of motors. A permanent magnet, M, causes a magnetic flux across the air gap G, and situated in this gap is a bobbin, B, on which is wound a number of convolutions or turns of copper wire. The bobbin is made to revolve on jeweled bearings. The object of the jewel bearing is to have the instrument as much devoid of mechanical friction as possible. Two springs, S, one above and one below the bobbin, carry the current to the movable part of the meter. If the current is now caused to flow around the coil of wire, it will produce a torque or twist which will move the bobbin again the two hair springs, S. Like magnetic poles repel each other and unlike magnetic poles attract each other. The current flowing around the

movable bobbin produces magnetism, and the quantity or strength of magnetism so produced is proportional to the amount of current which the pressure or voltage

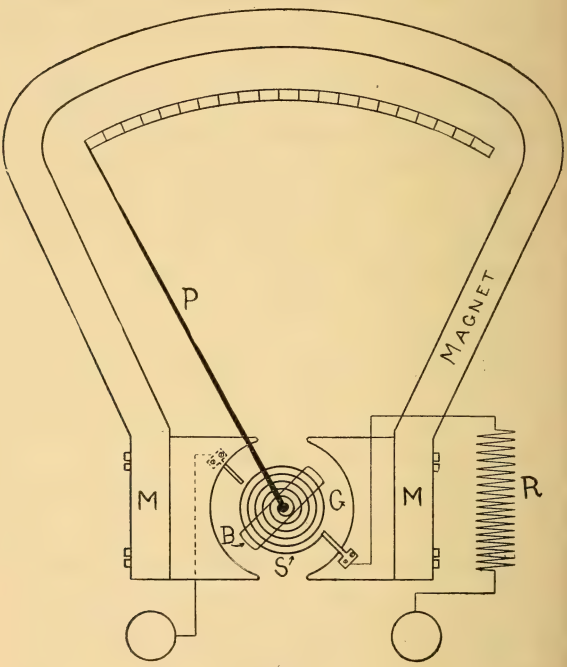


FIGURE 77.

will force through the winding of the movable bobbin so that the bobbin will continue to move until the torque exerted by the current equals the counter torque exerted by the spiral springs. A pointer, fastened to

the shaft upon which the bobbin is mounted, passes over a graduated scale and indicates the pressure or volts. The capacity of this meter in volts will vary as the resistance of the wire connected in series with the bobbin varies. We will assume that we have a meter whose pointer reads from 0 to 125 volts. If we desired this same meter to read from 0 to 250 volts, we would put a resistance in the meter which would be twice as great as the one contained in the meter when reading from 0 to 125 volts. The permanent magnet of this meter is made of Tungsten steel, and this steel is artificially aged so that when the instrument leaves the factory the magnetizing power of the magnet will remain constant for a number of years. The current is brought into the instrument through the binding posts A and C, but before passing through the wire on the bobbin the current must pass over a path of very high resistance, R. This resistance is proportioned to the amount of pressure the meter is made to indicate, and in commercial construction instead of making bobbins of variable resistances, the bobbins are all made alike, and this dead resistance, R, is varied to comply with the pressure that it is to indicate with the instrument. In voltmeters used on a 500 to 600 volt circuit, this resistance will measure from 65,000 to 75,000 ohms. The current which flows through the winding on the bobbin at full voltage is very small, and when registering 110 volts amounts to about one seven-hundredth of an ampere. Since it is the number of ampere turns that produces the magnetic density in an electro magnet, it can be seen that even one seven-hundredth of an ampere, if passed around a bobbin a considerable number of times, will produce quite a strong magnetic flux and pull. Voltmeters are often

referred to as being "dead beat." What is meant by dead beat is the tendency of the pointer to move from one position to another with very little or no swinging to and fro. In this type of voltmeter this dead beat effect is produced in the following manner: The core of the bobbin B being constructed of copper, when a current flows over the winding of the bobbin and causes it to revolve, eddy currents are produced in the copper (in much the same way that current is produced in the revolving armature of a dynamo), and these eddy currents tend to arrest the motion of the bobbin. In the best voltmeter construction the resistance wire used is made of a metal which will not vary much in resistance at different temperatures. It can readily be seen that, were a meter which was constructed and correctly calibrated at 70° F., surrounding temperature, mounted on switchboard in an engine-room with the temperature at 90° or 95°, the meter would not register absolutely correct, because the resistance of the wire would be considerably increased, due to the increase of the surrounding temperature. The effect of this would be a smaller flow of current at an equal voltage through the bobbin in the meter, and consequently a smaller amount of magnetism and a lower reading of the instrument.

We will assume that a copper cable of about the size of one's wrist is conducting a current of about three thousand amperes. Now, if a monkey wrench or hammer were to be lying within a few inches of this cable, before current was flowing, the monkey wrench or hammer would be attracted to the cable. The rapidity with which the monkey wrench would be attracted to the cable would be proportional to the weight of the iron in the wrench and the amount of the

current flowing through the cable. This, I think, will explain an electrical phenomenon which will assist us to understand what are called the magnetic vane voltmeters and ammeters. This principle is shown in Fig. 78.

A certain amount of current passing over the path A, which consists of several turns of wire, will attract an iron form, B, mounted on the spindle with the

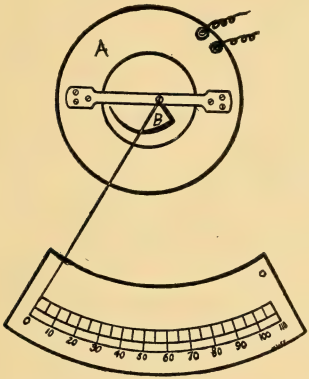


FIGURE 78.

pointer. The attraction will be proportional to the amount of current flowing over the copper conductor. The advantage of such an instrument is its simplicity, but the disadvantage is its inaccuracy. Its simplicity is apparent, and its inaccuracy is due to the residual magnetism that remains in the iron part B when the current through the conductor has been reduced. When the indicator is caused to move upward on the scale, the instrument will register practically correct,

but as the flow of current over the conductor A diminishes or decreases, the residual magnetism remaining in the iron part B will have a tendency to cause it to lag back. Amperemeters are constructed on practically the same lines as explained in the construction of voltmeters, except that in ammeters the whole current to be measured passes through the coil A, this coil being made of comparatively few turns of large wire, while in voltmeters the resistance is very high. Ammeters are placed in series with one of the leads and voltmeters in shunt with the current to be measured. In some ammeters a resistance block, usually called a shunt, is employed, over which the main current is caused to flow, and the ammeter is connected to both ends of this resistance block. In this way only a very small portion of the total current is caused to flow through the ammeter. In this case a milli-voltmeter, with the scale graduated to amperes, is employed. By Ohm's law we know that the voltage is equal to the current times the resistance, $E = CR$. The resistance remaining constant, the voltage is proportional to the current, so that the amount of current sent through the milli-voltmeter or ammeter is exactly proportional to the current flowing through the shunt. Fig. 79 shows connections for ammeters which carry the entire current and those used with a shunt.

The object of such a construction is apparent. In the installation of the switchboard, where each ammeter registers several thousand amperes, it is not necessary to construct the large conductors in such a manner that the total current is caused to flow through the ammeter. For each 1,000 amperes passing over the shunt only about one-half an ampere will pass through the ammeter, and the little bobbin will then

cause a deflection of the pointer in the meter and the pointer will register 1,000 amperes. Meters of this description are usually connected to their resistance blocks by a pair of No. 16 flexible lamp cords. When installing meters of this class, never cut off any of the

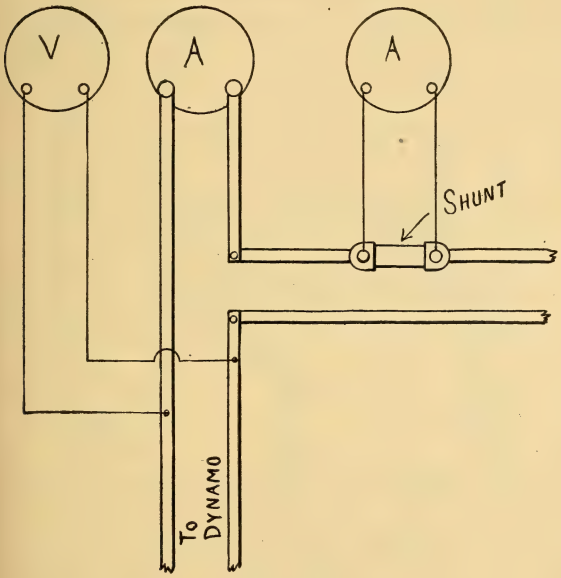


FIGURE 79.

flexible cord which is supplied with the ammeter, as the resistance of the cord becomes a part of the resistance in the meter. By cutting off some of this cord it can be readily seen that the meter will register more current than it should.

Another kind of meter is constructed on the solenoid principle, and is shown in Fig. 80. In this instrument the helix is a bare copper wire and is wound in an open coil form. It is curved in the shape of a segment of a circle, the center of which is at the pivot on which the needle is suspended. The pointer or needle is attached and projects downward to the scale. The helix is made of copper rod or is cast to the shape

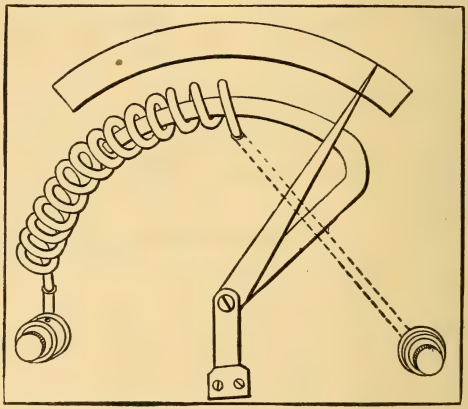


FIGURE 80.

required. Being of an open coil type, it is not necessary that it be insulated with insulating material because the air spaces between the turns becomes the insulation. Although not the best insulator by any means, there are few substances which possess better insulating qualities than air, although on account of its absorption of moisture, it becomes often a much poorer insulator than many other materials. In this type of

instrument it will be seen that as the number of amperes flowing over the coil is increased it produces an increased electromagnetic pull on the iron section or core entering it. As this electro magnetic pull is

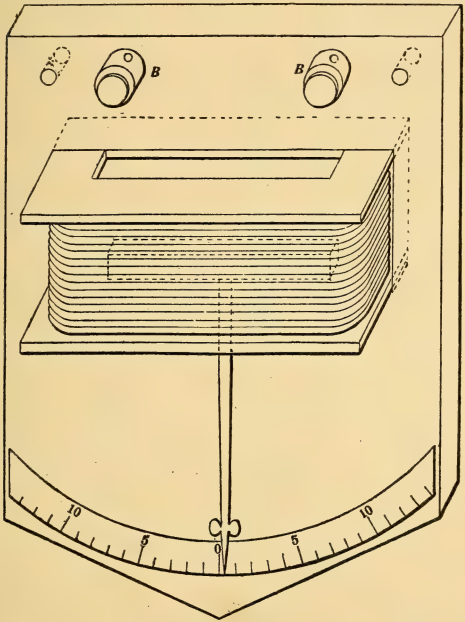


FIGURE 81.

increased, the core moves up into the helix and causes a deflection of the pointer across the scale on the instrument. This type of instrument has the same objection as that of the magnetic vane instrument,

namely, residual magnetism of the iron, and hence error in the reading while the current flowing is being diminished.

Another style of simple ammeter or voltmeter is shown in Fig. 81. This instrument consists of a frame made of non-magnetic material, around which the wire is wound, the ends of the wires being connected to the binding posts. The armature of this instrument, as in all other similar instruments, is connected to the pointer, and may be constructed of several pieces of iron. The principle of its working is similar to that described above, in that the armature tends to set itself at right angles to the wire through which the current passes. This style of instrument is used where current is liable to flow in either direction.

A simple form of meter for measuring current is shown in Fig. 82. Here we have an amperemeter which consists of a strip of copper fastened to a block of wood or other insulating material, as shown at A. A piece of magnetized steel, B, to which a needle, C, is attached, swings on a pivot or shaft which is suspended at the bridge D. A scale is provided from which the number of amperes flowing can be obtained. The needle is rigidly attached to the magnetized steel B and moves with it. The action of this instrument is as follows: When a magnetized piece of steel is brought near to a conductor through which a current of electricity is passing, the magnetized steel tends to set itself at right angles to the direction of the current. The stronger the current becomes, or the more highly magnetized the piece of steel may be, the nearer to a position of right angles the armature will assume. It is not practical to use this construction of an instrument to cover a range of more than one-half of a right

angle, for when the needle moves through an angle of about 50 degrees, it will require a much greater increase of current in proportion to the movement to obtain the deflection and the additional degree of the indicating needle. Such an instrument as the above may also be used to determine the direction of flow of

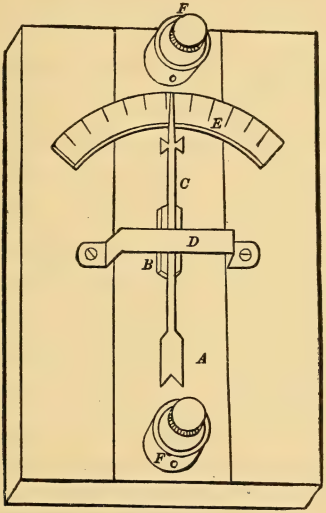


FIGURE 82.

current in a wire and is sometimes quite convenient on arc circuits which are liable to have their currents reversed either by wrong plugging of the board or the reversing of polarity in the dynamo.

Voltmeters and ammeters used with alternating currents must, of course, differ in some respects from

those employed for continuous currents. Alternation of the current does not permit the utilizing of the magnetic effect of the current to the same extent or in exactly the same manner as continuous currents, but when the cores of magnets are built up of soft iron wires of small diameter, the resulting attraction between coil and core is similar, though not so strong as between a coil carrying direct current on a solid iron core.

Another type of ammeter and voltmeter used with alternating or direct current is known as the hot wire instrument. A rather long, thin platinum wire is placed in the circuit and so arranged that its elongation or expansion resulting from the heating effect of the current passing over it is made to operate a pointer mounted on a jeweled bearing. These instruments absorb but little current and are claimed to be permanently correct. This class of instrument may be used on either direct or alternating current, and when used on alternating current the frequency or alternations make no difference in the operation of the instrument. It is also unaffected by external magnetic fields, such as a neighboring dynamo or motor, and can be used close to a wire conducting current without being affected in its accuracy. When used as an ammeter it is connected in shunt with a resistance placed in the main circuit in the same manner as described for direct current ammeters, and in this way but a very small proportion of current is made to pass over the instrument. Separate resistances are also furnished with the instruments; so that by connecting these in series with the instrument they can be used over a very wide range.

Wattmeters. A few years ago, where current was sold by central stations to consumers, or in any other

place where it was desirable to measure the power furnished in the form of electricity, there were several kinds of differently constructed meters used to measure the amount of current. Some of these meters were based on the chemical action of the current; the current in passing to the work depositing metal from one plate to another. The plates or terminals of the meters were weighed before being placed in the circuit and again weighed on being taken out, the amount of metal having been deposited determining the amount of current used, as explained in the fore part of the book. Of late, however, most of the recording wattmeters in use are operated on the principle of the Thomson wattmeter. As has been explained under the definition of units, the work done (watts) is equal to the current (amperes) multiplied by the electromotive force (volts), or $W = C \times E$. For a wattmeter to register correctly it must take a record of the volts and amperes.

The Thomson wattmeter is simply a small motor in which the armature is used as a voltmeter and the fields as an ammeter. The armature is wound with fine wire and is connected to a small commutator made up of metal bars. Two very thin metal brushes bear on this commutator and carry the current to and from the armature. The armature is connected across the mains in just the same way as a voltmeter would be connected. The fields are wound with a coarse wire and are connected in series with the main circuit, thus acting as an ammeter. It can readily be seen that with the armature influenced only by the voltage, and the fields by the current passing through the mains, the two acting together will correctly measure the power supplied. As the voltage rises or lowers, the speed of the armature will be affected accordingly, and as the current

through the fields varies the electromagnetic effect produced by the fields and in which the armature revolves will vary, thus also varying the speed. By reference to Fig. 83, the fields F F are connected in series with one of the mains and the armature A is

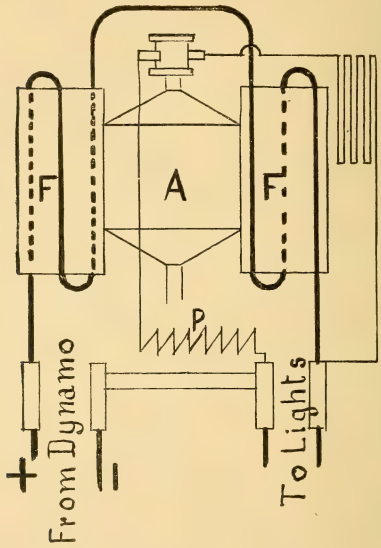


FIGURE 83.

connected across the mains. Fig. 84 is a simplified diagram. Attached to the shaft on which the armature rotates is a copper disc which revolves between the poles of a permanently magnetized steel magnet. Eddy currents are generated in this copper disc as the

armature rotates, thereby acting as a brake against which the armature must work. Connected to the top of the shaft is a train work of wheels which move small pointers over the dials on the face of the instrument and record the amount of current which has passed through the meter. As no iron is used in either the armature or fields of the motor, the meter can be used on either alternating or direct current.

In Fig. 85 we show a two wire meter with the case removed.

In Fix. 86 a three wire meter is shown.

Directions for Reading Meter Dials. To correctly read the sum indicated on the dial of a recording meter, the

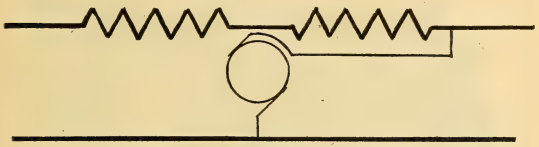


FIGURE 84.

directions given herewith should be thoroughly understood and carefully followed.

The figures (1,000, 10,000, etc.) under or over each dial refer to a complete revolution of the hand at that dial.

Therefore, each division on the dial to the extreme right indicates not one, two, three, or four thousands of units, but one, two, three, or four hundreds of units.

A complete revolution of the hand counts one thousand, and will have moved the hand on the second dial one division. Thus in reading Diagram No. 6, Fig. 87 the first dial (that on the extreme right) indicates 700, not 7,000.

A hand to be read as having completed a division, must be confirmed by the dial before it (to the right). It has not completed the division on which it may appear to rest, unless the hand before it has reached

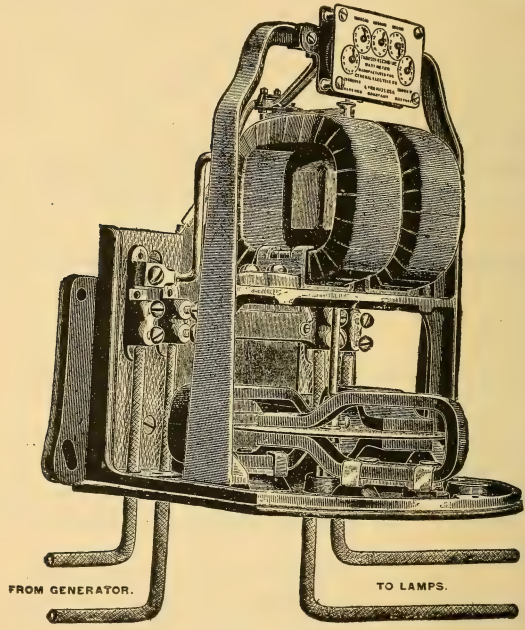


FIGURE 85.

or passed 0, or, in other words completed a revolution. For this reason it will be found easier and quicker to read a dial from right to left, as shown by reading Diagram No. 2, Fig. 87.

The first dial (the extreme right) indicates 900. The second hand apparently rests on 0, but since the first rests only on 9 and has not completed its revolution,

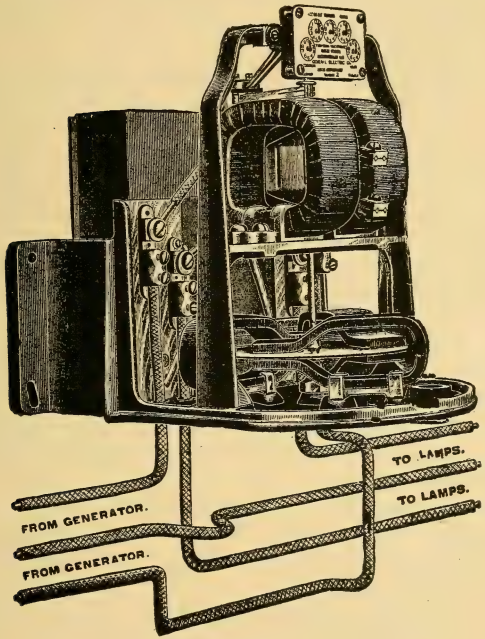


FIGURE 86.

the second dial also indicates 9. This 9, placed before the 900 already obtained, gives 9,900.

This is also true of dial 3. The second hand, at 9, has not quite completed its revolution, so the third has not completed its division, therefore another 9 is

obtained, making 99,900. The same is true of dial 4, making 999,900.

The last dial (the extreme left) appears to rest on 1, but since the fourth is only 9, the last has not completed its division, and therefore reads 0. The total reading is 999,900.

The hands are sometimes slightly misplaced. In Diagram No. 8 the first diagram (the extreme right) reads 0, which gives 000. The hand of the second dial is misplaced. As the first registers 0, the second should rest exactly on a division; therefore it should have reached 8, making 8,000. The third hand is apparently on 3, but since the second hand is at 8, the third cannot have completed a division and must, therefore, indicate 2. The two remaining dials are correct, and make a total of 9,928,000.

In Diagram No. 9, the second dial hand is misplaced, for since the first indicates 1, the second should have just passed a division. As it is nearest to 8 it must have just passed that figure. The remaining three dials are approximately correct. The total indication is 9,918,100.

In Diagram No. 10, the second and fourth dial hands are slightly behind their correct position, but not enough to mislead in reading. The total indication is 9,928,300.

By carefully following these directions little difficulty will be found in reading the dial, even when the hands become misplaced. .

Note whether there is a constant marked on the dial. If there is, multiply the dial reading by the constant. With constant ½, multiply by ½; that is, divide by 2.

The "constant" of a meter is the term applied when

No.1=1,111,100
No.2=999,900
No.3=1,000,100
No.4=9,999,400
No.5=909,100
No.6=99,700
No.7=9,912,100
No.8=9,928,000
No.9=9,918,100
No.10=9,928,300
1000000 100000 10000
THOMSON RECORDING
WATT METER
GENERAL ELECTRIC CO.
Watt Hrs. Constant Watt Hrs.

FIGURE 87.

the meter is constructed to run at a lower speed than what would be necessary to measure the true number of watts which has passed through it. For instance, if the constant is 2 and the meter has registered 5,000 watt-hours, then the meter having run only half as fast as it should, we multiply 5,000 by 2, which gives us 10,000 watts as the actual amount that has passed through the meter. This scheme becomes necessary in order to register a large amount of current with a meter small in bulk or size. For convenience the maker often takes a 220 voltmeter which would read the number of watts direct on the dial at 220 volts and sells it for a 110 voltmeter by marking a constant on the dial of the meter.

CHAPTER IX

Arc Lamps. The principle on which the arc lamp operates is shown in Fig. 89. Current is caused to flow from one carbon point to another through a space or gap between the carbons. The heat of the arc is sufficiently high to disintegrate the carbon and reduce it to a vapor, this vapor filling the space between the carbon points. The current passes over this space in a bow-shape path or arc, and it is from this fact that the lamp gets its name. The arc is constantly moving, and generally revolves around the carbon points. This can be easily seen by looking closely at a burning lamp through a smoked glass. After a lamp has been burning for some time on direct current the carbons assume the shape shown in Fig. 88, the upper or positive carbon assuming a cup shape, while the lower carbon generally burns to a point. This cup shape formation on the upper or positive carbon acts as a reflector to throw the light downward. The positive carbon burns away about twice as fast as the negative carbon and lamps must be trimmed accordingly. Sometimes the current feeding arc lamps (on direct current systems) becomes reversed, either through the dynamo reversing its polarity or through wrong plugging of the switchboard. The lamps will now burn "upside down," or, in other words, the bottom carbon will be the positive one. In such a case, if let go, the carbon holders of the lamp will be burned and the lamp will burn for only half the time for which it was intended, owing to the fact that the lower or negative carbon is only one-half as long as the upper or positive carbon. Such a

condition can be determined by either of the following ways: See if the light is being thrown downwards. See which carbon is burning away the faster. Raise the carbons and notice the formation of the carbon tips. When the carbons are separated it will be noticed that the tip of one carbon is considerably hotter than the other and is heated a longer distance from the point; this is the positive carbon.

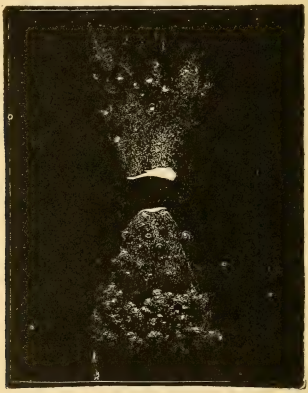


FIGURE 88.

The action of the arc lamp used on direct current constant current systems is shown in Fig. 89. Current passes through wire T and over the coarsely wound solenoid M, thence down to the carbon, across the arc or crater, into the negative carbon and out again on the wire T′. The regulating action is as follows: A coil M′, constructed of fine wire and of high resistance, is connected in shunt across the arc. The action of the current flowing through the solenoid M across

the crater or arc produces a magnetic pull on the solenoid core A and causes a separation of the carbons. As these carbons burn away the resistance across the crater increases and a very small portion of the main current is caused to flow through the shunt coil M'. The magnetic pull of the shunt solenoid overcomes that of the series solenoid with the result that the solenoid core A is drawn into coil M' and the upper carbon thus lowered, decreasing the gap at the arc. In this way a constant regulation is going on, tending to keep the two carbons at a uniform distance apart. The upper carbon rod is held by means of a clutch. When the carbons have burned away, so that the lowering of the solenoid does not lower them to the proper extent, the clutch is released and the carbon drops, thus feeding the lamp. Some lamps are manufactured wherein the lower carbon is positive. This causes the light emitted from the crater to be projected upwards. The arc lamp frame is supplied with a shade on which the light cast from the arc is reflected downward. The advantage of this system is to obtain a better diffusion and distribution of the light beneath the arc lamp. This lamp is not now generally used.

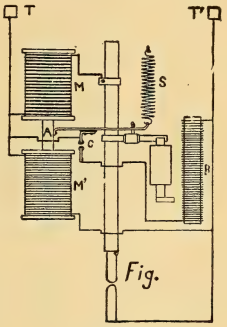


FIGURE 89.

Fig. 90 shows a diagram of connections for the improved Brush arc lamp. These lamps are used on constant current or series systems and their action is as follows:

The carbons should rest in contact when the lamp is cut out. When the switch is opened, part of the cur-

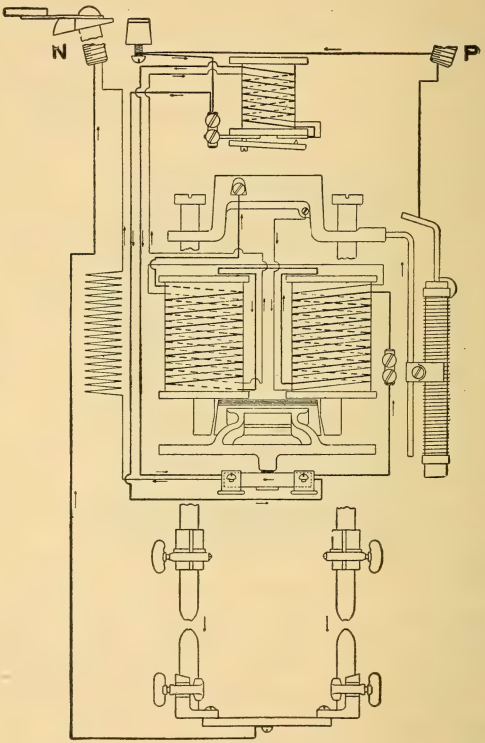


FIGURE 90.

rent from the positive terminal hook P goes through the adjuster to the yoke and thence through the carbon

rod and carbons to the negative terminal hook N. The remainder of the current goes to the cutout block, but, as the cutout block is closed at first, the current crosses over through the cutout bar to the starting resistance, and so to the negative side of the lamp. A part of it, however, is shunted at the cutout block through the coarse wire of the magnets and so to the upper carbon rod and carbons and out. This shunted current energizes the magnet and so raises the armature which opens the cutout and at the same time establishes the arc by separating the carbons.

The fine wire winding is connected in the opposite direction from the coarse wire winding, and its attraction is therefore opposite. When the arc increases in length, its resistance increases, and consequently the current in the fine wire is increased. The attraction of the coarse wire winding is therefore partly overcome and the armature begins to fall. As it falls, the arc is shortened and the current in the fine wire decreases. The mechanism feeds the carbons and regulates the arc so gradually that a perfect, steady arc is maintained.

The fine wire of the magnets is connected in series with the winding of a small auxiliary cutout magnet at the top of the mechanism.

This magnet, which also has a supplementary coarse winding, does not raise its armature unless the voltage at the arc increases to 70 volts. The two windings connect at the inside terminal on the lower side of auxiliary cutout magnet, and the current from the fine wire of the main magnets passes through both windings and then to the cutout block and so to the starting resistance and out.

If the main current through the carbon is interrupted (as by breaking of the carbons) the whole current of the lamp passes through the fine wire circuit. Before this excessive current has time to overheat the fine wire circuit, it energizes the auxiliary cutout magnet, and closes a circuit directly across the lamp through the coarse wire on the auxiliary cutout to the main cutout block, and thence to the negative terminal.

The auxiliary cutout operates instantly, and prevents any danger to the magnets during the short period required for the main armature to drop and throw in the main cutout. When the main cutout operates, the armature of the auxiliary cutout falls, because there is not sufficient current in that circuit to energize the magnet.

The voltage at which the auxiliary cutout magnet operates depends on the position of its armature, which is regulated by the screw securing the armature in position. It should not be adjusted to operate at less than 70 volts.

One of the three methods of suspension may be used for Brush lamps. If chimney suspension, which is the most common, is adopted, the wire, cable or rope used to suspend the lamp must be carefully insulated from the chimney. For this purpose a porcelain insulator should be inserted between the support and the lamp, as shown in Fig. 91.

Hook suspension may be used to advantage in some places, but great care must be taken to insulate the supporting wires from any conductors, as the hooks form the terminals of the lamps.

The most convenient arrangement for indoor use is to suspend the lamp from a hanger board. The porce-

rain base of the hanger board prevents short circuits or grounds.

A protecting hood is not necessary for outdoor use, as the lamp chimney and its base are one casting and effectually exclude rain or snow water.

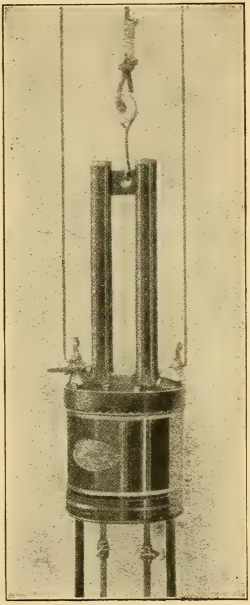


FIGURE 91.

The lamps run on circuits of 6.6 amperes for 1,200 and 9.6 amperes for 2,000 nominal candlepower. In case it is necessary to run a lamp on a circuit differing from the standard, the lamp may be adjusted by moving the contact on the adjuster. About one ampere either above or below the normal may be compensated for by this means.

Permanent adjustment for special circuits of variation greater than one ampere is made by filing the soft iron armature. The clutch should be so adjusted that the center of the armature is $\frac{3}{16}$ in. above the plate when the trip on the first rod is touching the bushing, and $\frac{1}{16}$ in. when the trip on the second rod is in a similar position. A small gauge is convenient for adjusting the clutch. The position of the trip of the clutch determines the feeding point of the lamp.

After thoroughly repairing and cleaning the lamp, it

should be run a short time before installing. Lamps should not be tested in an exposed place, as a strong draft of air will cause unpleasant hissing which may be mistaken for some internal trouble.

Lamps should not hiss or flame if good carbons are used. A voltmeter should always be used when adjusting or testing.

The lamp terminals are marked P (positive) and N (negative) and should be connected into circuit accordingly.

The carbons should be solid and of uniform quality. For the best results, the upper carbon should be 12 in. $\times \frac{7}{16}$ in., and the lower 7 in. $\times \frac{7}{16}$ in. The stub of the upper carbon may then be used in the lower holder when retrimming.

At each trimming the rod should be carefully wiped with clean cotton waste. If any sticky or dirty spots appear, which cannot be readily removed with waste, use a piece of well-worn crocus cloth, always being careful to use a piece of clean waste before pushing the rod into the lamp. It should never be pushed up into the lamp in a dirty condition.

The carbon rod may be unscrewed and removed by a small screw driver or small strip of metal inserted in the slot cut in the rod cap. The cap will remain in the hole through the yoke when the rod is taken out.

In Fig. 92 an interior view of the Thomson-Houston arc lamp is shown. This lamp is also used on constant current systems.

The lamps should be hung from the hanger boards provided with each lamp, or from suitable supports of wire or chain.

As the hooks on the lamp form also its terminals,

they should be insulated, where a hanger board is not used, from the chains or wires used to support the lamp.

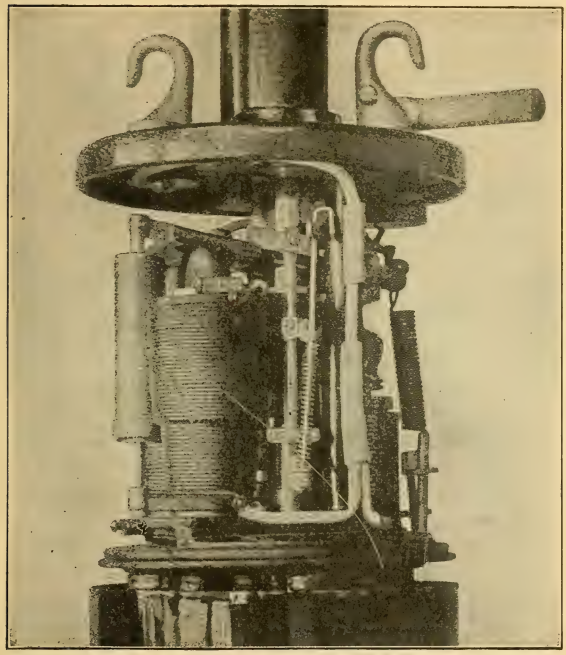


FIGURE 92.

When the lamps are hung where they are exposed to the weather, they should be covered with a metal hood, to prevent injury from rain and snow.

In such cases, care should be taken that the circuit wires do not form a contact on the metal hood and short circuit the lamp.

Before the lamps are hung up they should be carefully examined to see that the joints are free to move, and that all connections are perfect.

No lamp should be allowed to remain in circuit, with the covers removed and the mechanism exposed. Such practice is dangerous, and in violation of insurance rules.

The object of testing the lamps in the station is to find any defects, if such exist, and to test all the conditions of running before delivering them to customers. The lamps should not be hung up in their respective places in the external circuit, until everything is running with perfect satisfaction.

The tension of the clamp which holds the rod is adjusted by raising or lowering the arm at the top of the guide rod. (See Fig. 93.) If the tension is too great the rod and clutch will wear badly and the feeding will be uneven, causing unsteadiness in the lights. Too little tension will not allow the clutch to hold up the rod and any sudden jar to the lamp will cause the rod to fall and the light to go out.

The double carbon, or M lamp, should have the tension of the second carbon a trifle lighter than the first one.

When adjusting the tension, be sure to keep the guide rod perpendicular and in perfect line with the carbon rod; it should be free to move up and down without sticking.

The tension of the clutch in the D lamp should be the same as that of the K lamp. It is adjusted by tightening or loosening the small coil spring from

the arm of the clutch to the bottom of the clamp stop.

To adjust the feeding point in the K lamp, press down the main armature as far as it will go, then push

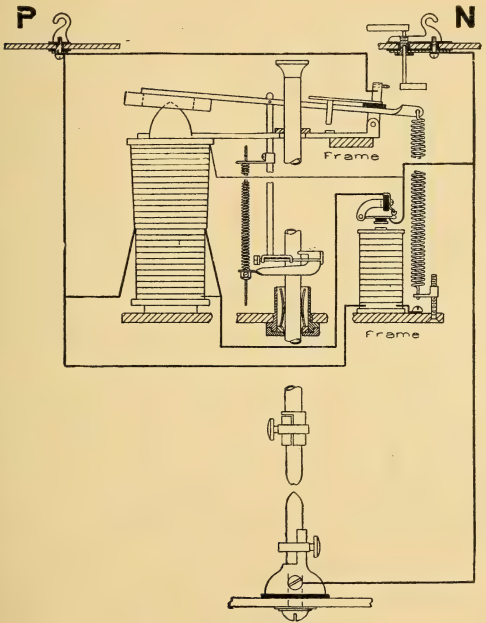


FIGURE 93.

up the rod about one-half its length, let go the armature and then press it down slowly and note the distance of the bottom side of the armature above the base of the curved part of the pole. When the rod

just feeds, this distance should be $\frac{1}{4}$ in. If it is not, raise or lower the small stop which slides on the guide rod passing through the arm of the clutch, until the carbon rod will feed when the armature is $\frac{1}{4}$ in. from the rocker frame at base of pole.

To adjust the feeding point of the M lamp, adjust the first rod as in the K lamp. Then let the first rod down until the cap at the top rests on the transfer lever. The second rod should feed with the armature at a point $\frac{1}{16}$ in. higher than it was while feeding the first rod, that is, it should be $\frac{5}{16}$ in. from rocker frame at base of pole.

The feeding point of the D lamp is adjusted by sliding the clamp stop up or down, so that the rod will feed when the relative distances of the armature of the lifting magnet and the armature of the shunt magnet from rocker arm frame are in the ratio of 1 to 2. There should be a slight lateral play in the rocker, between the lugs of the rocker frame.

The armatures of all the magnets should be central with cores, and come down squarely and evenly. There should be a separation of $\frac{1}{32}$ in. between the silver contact points, when the armature of the starting magnet is down. This contact should be perfect when the armature is up. The arm for adjusting the tension should not touch the wire or frame of the lamp when at the highest point. There should be a space of $\frac{3}{32}$ in. or $\frac{1}{8}$ in. between the body of the clutch and the arm of the clutch, to allow for wear on the bearing surfaces.

Always trim the lamp with carbons of proper length to cut out automatically, that is, have twice as much carbon projecting from the top as from the bottom holder. Always allow a space of $\frac{1}{4}$ in., when the lamp is trimmed, from the round head screw in the rod, near

the carbon holder, to the edge of the upper bushing, so that there will be sufficient space to start the arc.

The arcs of the 1,200 candlepower lamps should be adjusted to $\frac{3}{64}$ in., with full length of carbon. Arcs of 2,000 candlepower lamps should be adjusted from $\frac{1}{16}$ to $\frac{3}{32}$ in. when good carbons are used.

The action of a lamp that feeds badly may often be confounded with a badly flaming carbon. The distinction can readily be made after a short observation. The arc of a lamp that feeds badly will gradually grow long until it flames, the clutch will let go suddenly, the upper carbon will fall until it touches the lower carbon, and then pick up. A bad carbon may burn nicely and feed evenly until a bad spot in the carbon is reached, when the arc will suddenly become long and flame and smoke, due to impurities in the carbon. Instead of dropping, as in the former case, the upper carbon will feed to its correct position without touching the lower carbon.

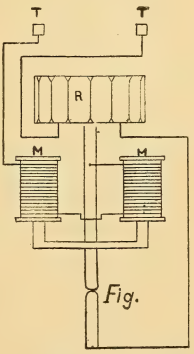


FIGURE 94.

In a series arc lamp the shunt coil is used to regulate the voltage over the arc. With constant potential arc lamps this shunt coil is not needed, owing to the fact that the voltage over the lamp is practically constant. Fig. 94 shows a diagram of an arc lamp for use on constant potential circuits. The upper carbon is supported by means of an iron yoke which forms a core to the two solenoids M M. Current entering binding post T passes through the windings of these two solenoids and

then through the carbons and through the resistance coil R to the other terminal of the lamp. The action of the lamp is as follows: Current passing over the solenoids M M is regulated by the resistance across the arc. This current produces an electromagnetic pull on the iron core and floats, magnetically, the core and upper carbon. When the carbons burn away at the crater the distance from point to point of the carbons is increased and a corresponding increase in resistance to the flow of the current takes place. This reduces the flow of current around the solenoids and correspondingly reduces the electromagnetic pull on the core; the iron core and carbon fall a slight distance by gravity. In so doing the distance at the crater is decreased and the flow of current increased, thus increasing the flow of current around the solenoids and drawing up the core and carbons. In this way a very nice equilibrium between gravity and magnetic pull is maintained. It will be noticed that this lamp has no automatic cutout as has the constant current arc lamp. In a series arc lamp when the carbons are all consumed, the automatic cutout closes the circuit from the positive and negative binding posts of the individual arc lamp, thereby maintaining a path through the arc lamp over which the current can continue to flow to supply the remaining arc lamps in the series circuit.

The series arc, as its name would indicate, is the most simple of all lighting circuits. The lamps are arranged so that all the current from the positive pole of the dynamo goes through each, and from the last on the conductor leads back to the dynamo. The series system is more generally used where it is desired to illuminate a large district, as in street lighting. It is

also used to some extent in store lighting, although the series arc is fast being replaced with the constant potential arc for this purpose.

In the low tension or constant potential arc lamp the use of a cutout mechanism is not necessary, because these lamps burn singly across the system of wiring, where a constant potential is maintained, and hence when the carbons are all consumed, current simply ceases to flow across them. In the open arc lamp the potential across the crater is usually from 45 to 50 volts, while in the inclosed arc lamp the potential across the crater is from 68 to 75 volts. This is due to the increased resistance through the crater, because of the peculiar nature of the gases emitted from the crater burning in a condition with practically no atmosphere. When such an arc lamp is connected across a 110 volt circuit, the lamp contains a resistance coil in the mechanism box over which the current must flow before producing the arc, R (Fig. 94). This resistance coil assists to reduce the pressure from 110 volts down to the pressure required by the arc or crater. If, for instance, the electromotive force across the wires supplying current to a low tension arc lamp is 110 volts and the pressure required to maintain the arc or crater is 70 volts, then the resistance coil chokes down the electromotive force from 110 to 70, or 40 volts. If the arc consumes 4 amperes of current then the loss is 4 (amperes) times 40 (volts), or 160 watts. This 160 watts is lost by heat radiating to the atmosphere from the wire of the resistance coil. The constant potential lamp is usually referred to as the low tension arc lamp. The high tension arc lamp generally burns with the arc in the open air, while the low tension lamp burns with the arc encased in a small glass bulb so arranged as to

permit the upper carbon to slide into the bulb in a manner that will maintain, as near as possible, a condition whereby the arc burns in a gas containing no oxygen. The enclosed arc lamp has the advantage of burning a considerable number of hours without being recarboned or trimmed; but it also has the disadvantage that the bulb enclosing the arc turns black after burning for some time, caused by the gases emitted from the arc. This renders the bulb partially opaque, consequently imprisoning a considerable quantity of useful light. Enclosed arc lamps are also operated in series systems, and where they are so used the objection of loss due to the cutting down of the voltage (as in constant potential lamps) is overcome. Enclosed lamps are also operated on alternating current systems.

The operation of the alternating arc lamp and the mechanism in the lamp is very similar to that of the direct current arc lamp, but the magnets instead of being constructed of solid iron, are laminated in a similar manner as the system of lamination explained in the construction of armatures. These laminated cores and other parts forming the magnetic circuit in the arc lamp are necessary to avoid eddy currents. The crater has neither a cup shape on the upper carbon nor a point on the lower carbon, because current flows through the crater alternately positive and negative with each alternation. In the alternating arc lamp the upper and lower carbons burn away with almost equal rapidity, and the same quantity of light is projected upward as downward.

In Fig. 95 is shown an arc lamp with case removed. The two upper coils are the coarsely wound series coils, while the two lower coils are the finely wound shunt coils. This lamp is adapted for an enclosed arc

bulb. The magnetically attracted cores are U shaped, and both cores are connected together mechanically by non-magnetic metal, such as brass or zinc, so that the magnetism set up in the shunt coils will not be affected by the magnetism set up by the series coils. This scheme is used in alternating current lamps, while in direct current lamps the cores are made of H shaped iron not laminated.

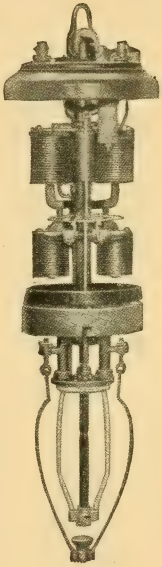


FIGURE 95

In Figs. 96 to 98 are shown three views of series enclosed alternating current arc lamps of the Western Electric Company.

Fig. 96. Side view of lamp, showing one series and one shunt spool, lever movement and adjusting weight. This weight is fastened upon a threaded rod, and the finest adjustment can be obtained by screwing the weight backward or forward. Threads can be clamped in position when the correct adjustment is obtained.

Fig. 97. Front view of lamp, showing shunt spools, supporting resistance and cutout. Note that lever carries no current when in normal working position, but that insulated bridge forms connection across two contacts, completing cutout circuit when in position shown in cut.

Fig. 98. Rear view of lamp, showing series spool, short circuiting switch and manner of suspending dash pot. Note that the dash pot is inverted, allowing such

dirt as may accumulate therein to fall out rather than in the dash pot.

The three cuts show the manner of suspending the spools and their accessibility, it being possible to remove any spool by simply taking out the two screws

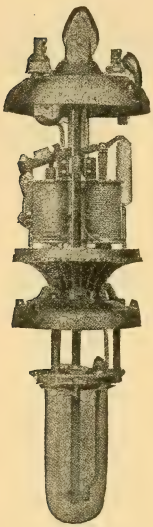


FIGURE 96.

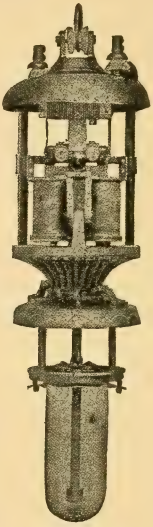


FIGURE 97.

FIGURE 98.

which fasten it to the frame, and lifting it off the lower support.

The carbons used in arc lamps are extremely hard and dense. They are made from a mixture of powdered gas house coke, ground very fine, and a liquid like molasses, coal tar, or some similar hydro-carbon, forming a stiff, homogeneous paste. This is molded

into rods or pencils of required size and length, or other shapes, being solidified under powerful hydrostatic pressure. The carbons are now allowed to dry, after which they are placed in crucibles or ovens, thoroughly covered with powdered carbon, either lampblack or plumbago, and baked for several hours at a high temperature. After cooling, they are sometimes repeatedly treated to a soaking bath of some fluid hydro-carbon, alternated with baking, until the product is dense as possible, all pores and openings having been filled solid. Arc carbons are often plated with copper by electrolysis, to insure better conductivity.

It is said that one 2,000 candlepower arc lamp will light in open yards 20,000 sq. ft.; in railroad stations, 14,000 sq. ft.; in foundries and machine shops, 5 000 to 2,000 sq. ft. Where good, even illumination is desired, it is advisable to use a greater number of smaller lamps evenly distributed.

CHAPTER X

Incandescent Lamps. As nearly every one is familiar with the construction of the incandescent lamp no detailed description will be undertaken, suffice it to say that the incandescent lamp comprises a carbon filament enclosed in a glass bulb from which the air has, as far as possible, been withdrawn, the carbon filament being soldered to the ends of small platinum wires entering the glass shell. Incandescent lamps can be burned either in series or in multiple; the multiple system being the most used. Series incandescent lamps are used to a considerable extent in the smaller towns for street lighting and also for the small miniature lamps burned in series on a constant potential system and used for decorative purposes. They are also used in street car lighting.

When incandescent lamps are to be used in series, they should be carefully selected; there is quite a difference in the current consumed by different lamps, even of the same make, and when they are all limited to the same current quite a difference in candlepower may be noticeable. Some will be above their rated candlepower and others below.

The resistance of an incandescent lamp when cold is very high, varying in the ordinary 16 candlepower 110 volt lamp from 600 to 1,000 ohms. When the lamp becomes heated, as when current is passing through it, the resistance reduces considerably, being in the 16 candlepower 110 volt lamp about 220 ohms.

The current required by the various incandescent lamps varies considerably for lamps of the same volt-

age and candlepower, but a good average which can be used in figuring currents is ½ ampere for a 16 candlepower 110 volt lamp and ¼ ampere for the 220 volt 16 candlepower lamp. The amount of power, in watts, consumed by a lamp is equal to the voltage multiplied by the current, or $W = C \times E$. A 16 candlepower 110 volt lamp taking ½ ampere would consume $110 \times \frac{1}{2} = 55$ watts, while a 220 volt lamp taking ¼ ampere would consume $220 \times \frac{1}{4} = 55$ watts. It will thus be seen that while the current and voltage may vary, the amount of power consumed will be approximately the same for all 16 candlepower lamps. Lamps are rated at a certain number of watts per candle, the amount varying from 3 to 4 watts for 16 candlepower 110 volt lamps. The proper lamp to be used varies according to the conditions. While less power is consumed in a 3.1 watt lamp, the life of the lamp is comparatively shorter, so that the lamps will have to be renewed oftener. With a 4 watt lamp a greater amount of current is consumed, but the life of the lamp is longer. Another point of great importance in burning incandescent lamps is the voltage. The table below shows what effect variation in voltage has on the candlepower and efficiency.

An increase in voltage increases the candlepower. This increases the efficiency and shortens the life as follows:

A lamp burning at—

Normal voltage gives 100 per cent. C. P. and consumes 3.1 Watts per C. P.

1	per cent.	above	normal	gives	106	per cent.	C. P.	and	consumes	3.	Watts	per	C. P.
2	"	"	"	"	112	"	"	"	"	2.9	"	"	"
3	"	"	"	"	118	"	"	"	"	2.8	"	"	"
4	"	"	"	"	125	"	"	"	"	2.7	"	"	"
5	"	"	"	"	132	"	"	"	"	2.6	"	"	"
6	"	"	"	"	140	"	"	"	"	2.5	"	"	"

A lamp burning at normal voltage should give its

full candlepower at its rated efficiency. A 3.1 watt lamp burning below its voltage loses its efficiency and candlepower as follows:

If burned—

1	per cent.	below	normal	it	gives	95	per cent.	C. P.	and	consumes	3.2	Watts	per	C. P.
2	"	"	"	"	"	90	"	"	"	"	3.35	"	"	"
3	"	"	"	"	"	85	"	"	"	"	3.5	"	"	"
4	"	"	"	"	"	80	"	"	"	"	3.6	"	"	"
5	"	"	"	"	"	75	"	"	"	"	3.75	"	"	"
6	"	"	"	"	"	70	"	"	"	"	4.	"	"	"
10	"	"	"	"	"	50	"	"	"	"	4.6	"	"	"

By referring to the table it will be seen that with the voltage raised 3 per cent. (on a 110 volt system to a little over 113 volts) the candlepower will increase 18 per cent., or in other words, a 16 candlepower lamp would be raised to nearly 19 candlepower. At the same time raising the voltage will decrease the life of the lamp. This is shown in the following table where, with an increase of 6 per cent. in the voltage, the life of the lamp is reduced 70 per cent. A lamp at normal voltage has 100 per cent. life.

The	same	lamp	1	per cent.	above	normal	loses	18	per cent.	life.
"	"	"	2	"	"	"	"	30	"	"	"
"	"	"	3	"	"	"	"	44	"	"	"
"	"	"	4	"	"	"	"	55	"	"	"
"	"	"	5	"	"	"	"	62	"	"	"
"	"	"	6	"	"	"	"	70	"	"	"

To obtain satisfactory results, the voltage should be kept constant at just the proper value.

Considerable heat is generated in an incandescent lamp, so that as a general rule it is a bad plan to use paper shades which come very close to the bulb. Where lamps are hung so that there is a liability of their coming in contact with surrounding inflammable material, such as in warehouses and store-rooms, it is a good plan to enclose the lamp in a wire guard.

The following table will prove a handy reference for estimating the number of lamps (8 to 50 C. P.) that can be run per horsepower or kilowatt. The table is

figured for theoretical values, so that the actual horsepower or kilowatts delivered must be used, or else values less than those given must be used to allow for loss in the lines.

Candle-power.	Efficiency.	Total Watts.	Per Horsepower.	Per Kilowatt.
8	3.5	28	26.6	35.7
8	4	32	23.3	31.2
16	3	48	15.5	20.8
16	3.1	50	14.9	20
16	3.5	56	13.3	17.8
16	4	64	11.6	15.6
20	3	60	12.4	16.6
20	3.1	62	12	16.1
20	3.5	70	10.6	14.2
25	3	75	9.9	13.3
25	3.1	77.5	9.6	12.9
25	3.5	87.5	8.5	11.4
25	4	100	7.4	10
32	3	96	7	10.4
32	3.1	99.2	7.5	10
32	3.5	112	6.6	8.9
50	3	150	4.9	6.6
50	3.1	155	4.8	6.4
50	3.5	175	4.2	5.7

The first column gives the candlepower. The second column gives the number of watts consumed for each single candlepower obtained, and is called the efficiency of the lamp. Multiply the total candlepower by the efficiency and you get the total number of watts consumed by the lamp. The fourth column shows the number of lamps per 746 watts, and the last column the number of lamps per 1,000 watts.

The current and watts consumed by 110 volt lamps of the different candlepowers are approximately given below.

4	candlepower	0.18	amperes,	20	watts
8	"	0.29	"	32	"
16	"	0.5	"	55	"
32	"	1.0	"	110	"

The light given off by an incandescent lamp varies according to the position from which it is viewed. In some makes of lamps most of the light is given off directly downward, while in other lamps the maximum light is given off in a horizontal direction. The best lamp to use must be determined by the location of the lamp and the place where the light is required. By the use of suitable reflectors or shades the light can be thrown in any direction desired. A 16 candlepower lamp if placed seven feet above the floor will light up a floor space of 100 sq. ft., providing the walls are of a light color. If the walls are of a dull color, or if a bright illumination is desired more lamps should be used. Glass globes placed over the lamps reduce the light to a considerable extent, as is shown in the following table:

Clear glass	10 per cent.
Holophane	12 "
Opaline	20 to 40 "
Ground	25 to 30 "
Opal	25 to 60 "

CHAPTER XI

The Nernst Lamp. Very recently a new type of electric lamp has been introduced which has a few characteristics of the arc lamp and many of the characteristics of the incandescent lamp. It is a lamp that can be successfully operated only on alternating currents. That part of the lamp from which the light is emitted is called the glower. The glower performs about the same functions as does the filament in an incandescent lamp.

In Fig. 99 a diagram of a six glower lamp is shown. The six glowers are shown at 6. These glowers are in the shape of small rods and are composed of an oxid which, at the normal temperature, is of very high resistance, the resistance being so high that practically no current can flow through them. When these rods become heated, the resistance reduces considerably, so that they will conduct current. The heaters which are composed of a considerable length of fine platinum wire embedded in porcelain, are shown at 5. The action of the lamp is as follows: Current enters at 1, and being unable to flow over the glowers on account of their high resistance, passes to the cutout 4′, then through the platinum wire of the heaters back to the other side of the cutout 4. As the platinum wire in the heaters becomes heated, the glowers, which are placed directly below them, also heat up and in time their resistance becomes so reduced that current will pass through them. The current will now pass through the glowers to what is known as the ballast, 7. This

ballast is composed of fine iron wire and its purpose is to steady the current through the glower. From the fact that iron wire increases in resistance with increase of current, this wire acts as a regulator, tending to cut

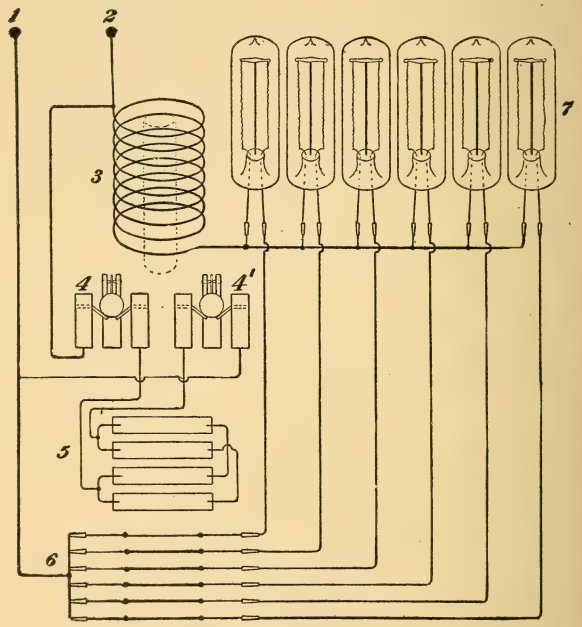


FIGURE 99.

down any fluctuations in the current strength. It will be noticed that there is a separate ballast for each glower. From the ballast the current flows around the coil of wire 3. Inside of this coil is an iron core which

moves up and down, and connected to the lower end of this core are the cutouts 4,4'. As the glower becomes heated, more current is sent around this coil, until it becomes of such strength that the core is drawn in, thus opening the cutouts. All of the current will now flow through the glowers. The Nernst lamp does not operate successfully on direct current,

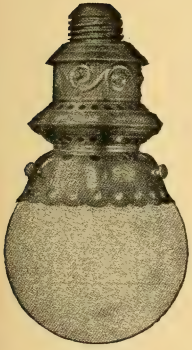


FIGURE 100.

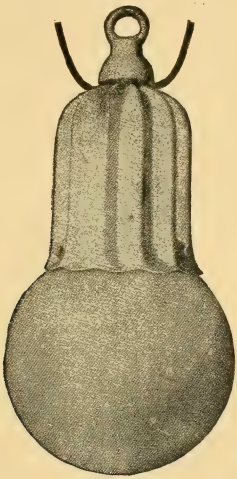


FIGURE 101.

due to the blackening of the glower caused by decomposition of the platinum contacts with which they are connected. These lamps are made in sizes of from 1 to 30 glowers, and they consume about 88 watts per glower. The light resembles very closely the light from a Welsbach gas burner, although the green tinge of the Welsbach is not present.

In Fig. 100 is shown the single glower lamp assembled, which can be inserted in an ordinary Edison socket.

In Fig. 101 the six glower lamp, with dome attached, is shown.

CHAPTER XII

Line Testing. In the operation of electric light and power circuits three principal causes of trouble are continually encountered. These are the open circuit, the short circuit, the ground, and also combinations of these, as there is nothing which prevents the existence of all three defects on any line at the same time. In order to study these properly, let us refer to Fig. 102, which shows an ordinary incandescent circuit equipped with the necessary cutout and a switch.

An open circuit may be caused by poor contact, or

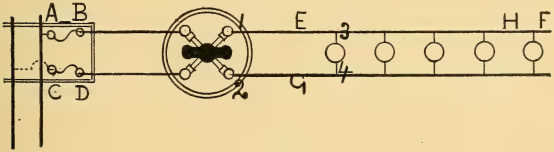


FIGURE 102.

failure to make any contact at all, of the fuse. If this is the cause, the light can be made to burn by connecting the fuse terminals A and B or C and D by means of short pieces of wire. Such wire must, however, be used only for an instant to make sure of the trouble, and proper fuses must then be provided. Another method of locating an open circuit in the fuse consists of moistening the finger tips and placing the tips of two fingers of the same hand on B and D. If the fuses are in order, a slight shock will be felt; this method is applicable only on low voltage systems and must never be used where the voltage exceeds 250.

If the fuses are found all right, the next place to look for the cause of an open circuit is at the switch. The contact points of switches are often so badly burned or covered with dirt and grease that they do not make proper connection and hence the lights will not burn.

The switch can be tested with the fingers just as we tested the cutout, and if the shock is felt the line is all right to this point. In testing the switch, be sure you test at the proper point (1 and 2) in the figure which shows a switch, the blades of which cross. Some switches make connection straight along without crossing. In testing with a wire, as shown above, be very careful not to connect the points 1 and 2 at the switch, or you will have a short circuit.

If the line is found alive at the far side (points 1 and 2) of the switch shown, and still the lights do not burn, it is quite likely that there is a broken wire between the switch and the lamps. This break in the wire is not always visible, as often the wire is entirely concealed, and even when the wire is in plain view, the break may extend only to the copper and leave the outer insulation apparently perfect.

If we are dealing with concealed wires that appear only where the lights are connected, we must first examine the connections at all such places and see whether they are in good order. If we find nothing wrong there we may proceed to locate our open circuit (which we shall assume to be at E) by the following method: In place of one of the fuses AB or CD, connect any incandescent lamp (if plug cutouts are used the lamp can be screwed in instead of the plug). Now connect a wire from 1 or 2 of the switch to 3 or 4 of the nearest lamp.

If we happen to connect our wire from 1 to 4 we

shall make a short circuit and the lamp at the cutout will burn at full candlepower, but none of the other lamps will burn at all. Now disconnect the test wire from 4 and connect it at 3; if the broken wire is at E, as we have assumed, all the lights will now burn in series with the lamp in the cutout. If there are but few lights connected in the circuit, this lamp will burn at about half candlepower; if there are many lamps connected it will come nearly to full candlepower, and the lamps in the circuit will show nothing.

If instead of an open circuit the cause of our trouble is a short circuit, it will first make itself evident by a burned out fuse in the cutout at AB or CD.

A little experience will soon enable one to judge whether a burned out fuse is due to an overload or a short circuit; the damage to terminals and the evidence of burning will be much greater from a "short" than from a slight overload.

Often the current that "blows" the fuse will also burn out the wire which caused the "short," so that the line will seem perfectly clear when a new fuse is inserted.

If an inspection of the wires and apparatus does not reveal the location of the trouble, we may fuse up one side of the circuit and connect an incandescent lamp in place of the other fuse. If the "short" is still on, the lamp will burn at full candle power.

A short circuit may consist of anything of low electrical resistance that brings the wires of opposite polarity into electrical connection with each other. Thus, if the two points, F and G, although several hundred feet or even yards apart, were in connection with gas or water piping of low electrical resistance, all current would flow through the piping from F to G,

and there would be none to flow through the lamps. Short circuits are also often caused by small wires inside of sockets or fixtures coming in improper contact. In one instance a short circuit which caused a search of several hours was finally located in the butt of an Edison base lamp, the center contact piece of which had been put on crooked in such a manner that when the lamp was screwed into its socket this center piece made connection with opposite poles within the socket.

If a careful examination does not reveal the "short" it will be necessary to cut the wires, say at H; if this clears the line so that all lamps nearer the cutout than H burn, the trouble must be beyond H; if not, the line must be cut again nearer the cutout until finally the exact location of the trouble is found.

Any connection of any part of an electrical circuit to *earth* is called a "ground," and wires so connected are said to be grounded. One ground on a system will not necessarily do much harm or interfere with the operation of the system. It will, however, greatly increase the probability of electric shocks to people coming in contact with any part of the wiring. Also, if there is a ground on one side of a system, the appearance of a second ground on the other side of the system will be equal to a short circuit, if both are of low resistance, and probably cause the burning out of fuses or wires.

If a ground is of high resistance, it may merely waste energy through leakage of current; or it may cause slow destruction of a wire or sometimes a gas or water pipe by electrolytic action. Aside from direct contact with metal parts of buildings, the most prolific cause of grounds is found in dampness.

Grounds may be located by means of the Wheatstone

bridge, magneto or a common bell and battery. After removing the fuses from the grounded part of the system, connect one side of the apparatus to a good ground, such as a water pipe, and the other side to the system. Proceed in the same way as explained for short circuits; that is, cut the lines until the ground is located, or the line shows clear. Where the wiring is concealed and there are a number of switches controlling chandeliers, grounds can very often be located by switching off one fixture at a time, for when the grounded fixture is switched off the line will show clear.

To facilitate the discovery of grounds as soon as they come on, most switchboards are equipped with ground detectors of some kind.

The cheapest and easiest to install of these consists of two lamps in series, as shown in Fig. 103. So long

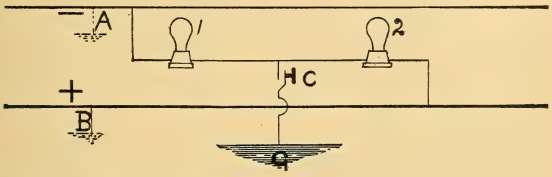


FIGURE 103.

as both sides of the system are clear of grounds, the lamps will both burn at equal candlepower (rather dim) no matter whether the buttom C be pressed or not. But should a ground come on the + wire, say at B, and the button C be then pressed, the lamp 2 will be deprived of current and lamp 1 will burn at full candlepower. In such a case the current passes from the + wire to the ground B, through the ground to C,

button C and lamp 1 to the – wire. Should a ground come at A, lamp 1 would be cut out and 2 would

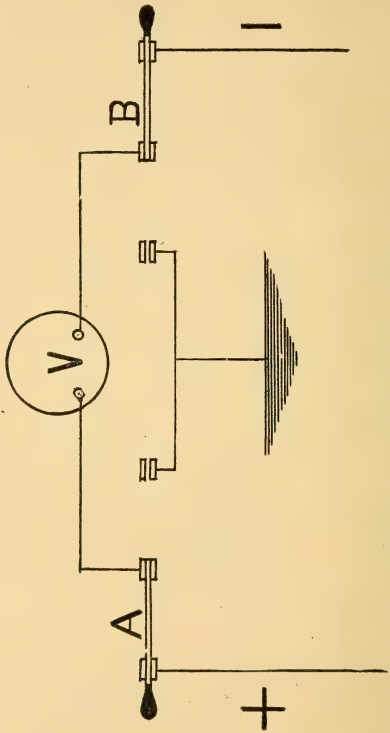


FIGURE 104.

burn at full candlepower. The great disadvantage of the lamp ground detector lies in the fact that it is not very sensitive; that is, unless the ground is of quite

low resistance the difference in the brilliancy of the lamps will hardly be noticeable.

A much more satisfactory arrangement is that shown in Fig. 104, where a voltmeter is connected for that purpose. With the two single pole switches A and B in the position shown, the voltmeter indicates the pressure of the dynamo; if B is thrown over, the current from the + wire passes through the voltmeter to the ground, and if there is a ground on the – wire it will indicate it. If B is thrown back and A over, a

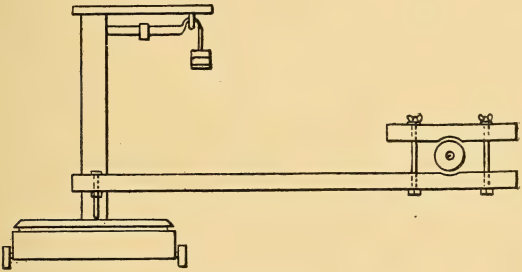


FIGURE 105.

ground on the + wire will be indicated. If the system is perfectly clear, the voltmeter will indicate nothing with either one of the switches thrown over. This test of lines and circuits should be quite frequently made.

Testing Efficiency of Dynamos and Motors. The simplest means of testing the efficiency of motors is shown in Fig. 105.

This is known as the Prony brake, and consists of a pair of clamps arranged for thumb screws and fastened to the pulley of the motor, and a set of scales.

We will assume that we are testing the efficiency of

a motor. We will arrange the clamps over the pulley as shown in the figure and on the long end of the clamp we will arrange a bolt, from which we may impart the pressure obtained to the platform of a pair of scales. In the circuit supplying the motor with current we will connect an amperemeter and a voltmeter. We will now start the motor and press down on the clamps by means of the thumb screw, until the mechanical energy expended is sufficiently high to cause the desired consumption of current shown by the amperemeter at the pressure shown by the voltmeter. With a tachometer or speed indicator we will find the number of revolutions of the motor per minute. When this has been done, we will take the weights on the scales and balance the pressure brought down on the platform. Now stop the motor. The weight indicated by the scales is that weight which the motor would have revolved through a circle, the radius, or half the diameter of which is the distance from the center of the motor shaft to the center of the bolt pressing on the scale platform, Fig. 105. To find the horsepower exerted, multiply the distance between the bolt and the armature shaft by 2. This will be the diameter of the circle described. Multiply this by 3.1416. This will be the circumference of the circle described. Multiply this by the number of pounds indicated by the scales, multiply this by the number of revolutions per minute, and divide the answer by 33,000.

Suppose your amperemeter registered 50.9 amperes and your voltmeter registered 110 volts. This would be $50.9 \times 110 = 5{,}599$ watts consumed. Divided by 746 watts, the electrical horsepower would be 7½ horsepower consumed.

Suppose the dynamometer proved that you obtained six actual mechanical horsepower. Then 6 divided by 7½ would be 80 per cent. efficiency which the motor would have for changing electrical energy into mechanical energy.

To test the efficiency of a dynamo we must first find how much power is being delivered to it by the engine. This is done in the usual manner by means of the indicator, etc. Having obtained this, it is simply necessary to connect an ammeter and voltmeter and, taking simultaneous readings of both, find the power given out by the dynamo by multiplying together the volts and amperes.

As an example, suppose we have found that our engine is delivering 40 H. P. while we are obtaining from our dynamo 200 amperes at 110 volts pressure. 200×110 divided by 746 will give us the electrical energy we are receiving; in this case a trifle less than 29.5 H. P. To find the efficiency of the dynamo we divide the power received from the dynamo by that delivered to it by the engine, 29.5 divided by 40 equals .737, which is the efficiency of this dynamo. When testing dynamos it is usual to provide an artificial load which can be kept constant. Large metal plates, preferably copper, are connected to the positive and negative mains of the dynamo and immersed in a barrel of water. The quantity of current that will flow from one plate to the other can be regulated by dissolving more or less salt in the water and by immersing the plates more or less and also by bringing them closer together. The greater the surface of the plates immersed in the water and the nearer they are brought together, the greater will be the current. Be very careful and do not let the plates touch each other. Before

accepting a new dynamo a test run of twenty-four hours at full load is usually made and the water rheostat need be used only to keep the load constant when lights are switched on or off.

Photometer. The amount of light given off by an incandescent lamp is measured in candlepower. To determine the candlepower of a lamp, an apparatus known as the photometer is used. Fig. 106 shows a diagram of what is known as the Bunsen photometer. S is a scale divided into inches, meters, or any suitable divisions, at one end of which is placed a standard lamp and at the other end the lamp to be measured.

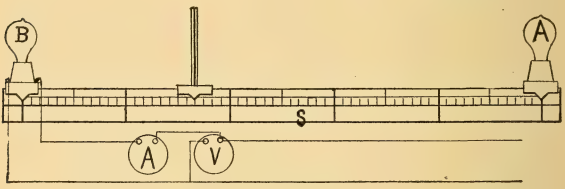


FIGURE 106.

A small screen, made of white paper having a grease spot in the center, is mounted on a stand so that it can be moved along the scale. To operate the instrument, move the screen to such a point that the grease spot becomes invisible from either side. The two candlepowers are now to each other as the squares of their distances from the screen. For instance, suppose the lamp A is a standard 16 candlepower lamp and at the point where the grease spot is invisible the distance from B to the screen is 20 in., and from A to the screen 40 in., then B is to A as 20 squared is to 40 squared, or as 400 is to 1,600 or one-fourth as great; therefore B is a 4 candlepower lamp. Care must

be taken that the two lamps are burning at just the proper voltage, otherwise the comparison will not be accurate. Instruments of the kind just described are made in a variety of different patterns, but their principle remains the same. Candlepowers may also be compared by a method known as Rumford's. Take a pencil or other opaque rod and place it in front of a white piece of paper or light-colored wall. Now place

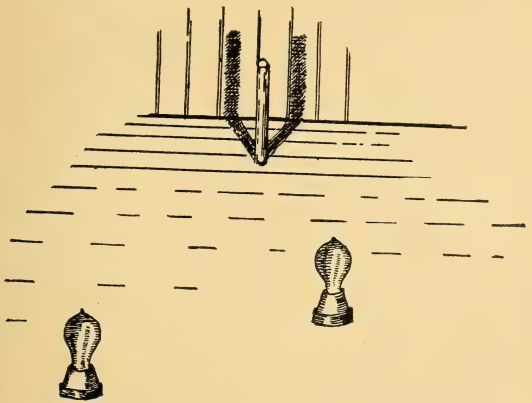


FIGURE 107.

in front of it, but separated so that there will be two separate shadows cast, the two lamps to be compared. By moving one of the lamps away from, or closer to, the screen, at some point the two shadows will become of the same density. Now measure the distances of the two lamps from the screen, and their candlepowers will be to each other as the squares of the distances; (Fig. 107).

If the current consumed by a lamp and the voltage maintained at its terminals are measured by an ammeter and voltmeter, as shown in Fig. 106, we need only find the watts (current times volts) and divide by the candlepower to find the efficiency of the lamp. If, for instance, the 4 candlepower lamp B is taking $\frac{1}{6}$ ampere at 110 volts, we have $18\frac{1}{3}$ watts expended on it; this divided by the candlepower 4 shows an efficiency of $4\frac{7}{12}$ watts per candle.

CHAPTER XIII

Storage Batteries. The storage battery is often referred to as an accumulator. An accumulator is an appliance for storing electricity. It depends upon the chemical changes undergone by certain substances when subjected to the action of an electric current. Strictly speaking, it is not correct to say that electricity is stored in an accumulator, although as far as external results is concerned such appears to be the case. What it really does is this: The current flowing into the accumulator produces a gradual chemical change or decomposition of the active elements of which the battery is constructed. This change continues to take place as long as the charging current is applied. This is known as electrolytic action. As soon as the current ceases, so also does the chemical decomposition of the elements cease, and if the terminals be then connected by a wire, a reversal of the chemical process commences. Particles gradually reform themselves into original chemical combinations, and by so doing produce a current of electricity which flows in opposite direction to that originally used for charging.

An early form of accumulator, though more of experimental than practical interest, was Grove's gas battery. This was composed of a series of cells, each cell comprising two tubes, closed at the upper ends, and dipping down into a glass jar containing acidulated water. Each tube had a platinum wire fused into the closed end, from which a strip of platinum foil extended downwards into the liquid. The outer ends

of the platinum wires were provided with terminals, by means of which several of these cells were connected together. A charging current was then applied and resulted in the gradual decomposition of the water in the various glass jars. Hydrogen collected on one of the platinum plates in each of the cells and oxygen on the other. If after a short time the charging source was disconnected from the wires joined to the outer terminals of the cells and a galvanometer substituted, it was found that a current would then flow in the reverse direction until all the separated hydrogen and oxygen gases had recombined to form water again.

From a practical point of view the gas battery was deficient, inasmuch as it would only supply current for a very short time, and several workers set themselves the task of contriving an arrangement to obviate this defect. The most successful of these early workers was Plante, and he found in the course of his experiments that the best results were to be obtained by using lead plates or electrodes in a dilute solution of sulphuric acid. He made a cell by taking two long strips of sheet lead, placed one over the other with pieces of insulating material between, and coiling these up into spiral form. These plates were provided with separate terminals and were placed in a jar containing a solution of sulphuric acid. The action of the charging current was to decompose the water in the solution, the oxygen combining with the metal of the positive plate and thus forming peroxide of lead, whereas the hydrogen was simply deposited on the negative plate and there remained in gaseous form. On discontinuing the charging current, the hydrogen combined with the oxygen in the solution to form water again, while the peroxide of lead was deoxidized,

the lead remaining on the surface of the plate as spongy lead, and the oxygen reëntered the solution to compensate for the oxygen which was extracted therefrom by the hydrogen in forming water. Plante found that this method of construction enabled him to get an electromotive force of from 2 to 2.5 volts, as against 1.47 volts given by Grove's gas battery.

Plante's experiments did not, however, terminate with this achievement, and he next introduced a method for considerably increasing the available metallic surface of the electrodes. This plan is known as "forming" the plates, and consists of repeating for a considerable time the following series of operations: (1) charge the accumulator, (2) discharge ditto, (3) recharge, but with the charging current entering in the reverse direction, (4) again discharge. This series of reversals in charging and discharging, if kept up for several days, has the effect of causing the lead plates to become very porous or spongy in character, and, therefore, by reason of the additional surface of contact between electrolyte and electrode thus provided, enables the cell to retain a much greater charge than it would otherwise.

It is not difficult to see that this work of forming is of a somewhat tedious and expensive character, and with the object of reducing this process to a minimum, another inventor, Faure, conceived the idea of using plates coated with a paste of lead-oxide, a plan which made it possible to use an accumulator with success after being charged only two or three times. When first introduced, some difficulty was found in making the lead-oxide paste adhere properly to the plates, and various means were devised to overcome this drawback. Scratching and indenting the lead plates was tried,

but this was ultimately superseded by the plan of making perforated plates in the form of grids, the paste being pressed into the perforations. With various slight modifications, in the shape of perforations, this device has been found to answer exceedingly well, and is now very generally adopted.

When an accumulator is freshly charged, it would be found to have an electromotive force of about 2.25 to 2.5 volts, but after being used a short time this falls to about 2 volts, at which figure it remains until the cell is nearly exhausted. For many purposes, however, a higher voltage than this is required, and it then becomes necessary to have several cells joined in series, so as to give a total voltage equal to the number of cells multiplied by 2. Thus 20 cells of 2 volts each, if joined in series, would give an electromotive force of 40 volts; 50 cells would give 100 volts, and so on.

The quantity of current which a cell will accumulate or store depends upon the area of its plates; the larger the plates the greater the capacity of the cell, and the higher the permissible rate of discharge. As it is not always convenient to use very large plates where great capacity is required, the same result may be obtained by using a number of small plates to increase the available plate surface, but in such cases the plates must be connected in parallel. That is, the positive plates must all be connected to one terminal, and the negative plates all to the other terminal, thus forming practically two plates divided into a number of branches.

The capacity of an accumulator is usually measured in ampere hours. Thus an accumulator which will discharge a current of ten amperes for one hour, or of

five amperes for two hours, or of one ampere for ten hours, is said to have a capacity of ten ampere hours. As a general rule, it may be estimated that an accumulator has a capacity of six ampere hours for each square foot of positive plate surface.

For charging storage batteries the shunt dynamo is generally used, and the voltage must be kept as nearly constant as possible. Fig. 108 shows a very simple installation where the battery is intended to be charged during the running time of the dynamo and to carry the lights during such time as the dynamo is not in

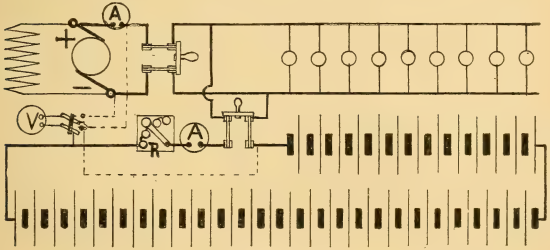


FIGURE 108.

action. The ammeter A, in the battery line, should be of a kind which indicates the direction of the current passing through it. The rheostat R is used to regulate the charging current and the voltmeter V is connected so that either the voltage of the dynamo or the battery may be taken. In addition to this voltmeter a low reading meter should also be provided to test single cells. An automatic circuit breaker is also often provided to open the circuit should the current through it flow in the wrong direction. Should, for any reason, the voltage of the dynamo fall below that

of the battery while charging, the battery would begin to discharge through the dynamo. Where it is important that the voltage supplied by the battery shall be at the same voltage as that supplied by the dynamo, a "booster" is employed to help charge the battery. Such a booster increases the electromotive force at the terminals of the battery sufficient to allow it to be charged to the full pressure of the dynamo. In setting up and charging storage batteries, detailed instructions should be obtained from the makers and rigidly followed.

CHAPTER XIV

Electrolysis. Electrolysis is chemical decomposition effected by means of the flow of an electric current. By electrolytic action it is possible to deposit metals, such as gold, silver, nickel, etc., over the exterior surface of other metals. This process is ordinarily called nickel plating, gold plating, etc., and is carried on by means of tanks in which there are liquids holding in solution some of the various metallic salts. By placing over these tanks a bar or number of bars made of brass or copper, we may hang articles from these bars by means of wires, so that they are submerged in the solution. Now by using a dynamo whose output is low in pressure or electromotive force and high in quantity or amperes, and connecting the positive or outgoing terminal of this machine to a piece of metal, such as copper, nickel, gold, or silver, and submerging this metal in the liquid contained in the tank, the flow of current from this piece of gold or silver into the liquid or bath will carry with it, by electrolysis or electrolytic action, some of this gold or silver and deposit it on the articles suspended in the liquid, from the brass or copper bars to which the negative terminal of the plating dynamo is connected. The use of the bath containing metallic salts reduces the resistance from the metal to be deposited on the articles that are to be plated, which are the negative electrodes. This effects an equal deposit of metal over the entire surfaces being subjected to the electrolytic or plating action.

Where it is desired to cover such metals as steel or

iron with silver or gold, it becomes necessary to subject the articles to be plated to what is called a striking bath. This striking bath consists of a system of electrolytic action as above described, where copper is first deposited over the surfaces of iron or steel. The more precious metals will distribute themselves over this copper surface more uniformly and in a finer grained manner than if the article had not been copper plated first. After the plated article has had sufficient metal deposited on its surface, it is put through a buffing and polishing process for its final finish.

Electrolysis has also been applied where it is desired to reclaim the precious metals from ores without smelting them. This method consists of immersing the ore in tanks filled with a solution. The ore receives current from the positive element of a dynamo through the liquid solution, and the metal in the ore is deposited on the negative plate in the vat, which is connected to the negative terminal of the dynamo. Thus by employing a process similar to electro plating it is possible to extract the metal from the ores in almost its pure state from the negative plate. The solution mentioned is water in which various kinds of metallic salts have been dissolved which bear a chemical relation to the metals to be extracted.

This short description will assist in explaining how electrolytic action takes place in water and gas pipes buried under the surface of the ground, when, for instance, electric railroads, operated in the vicinity are not properly constructed. In the construction of an electric street railroad or trolley line the generators are connected to the trolley wires usually at the positive terminals of the dynamos.

The current passes from the trolley line through the

car to the rails and back to the negative pole of the dynamo. If the rails are not of sufficient carrying capacity, or if there is a pipe line of better carrying capacity near the rails, it is quite certain that some of the current will be carried by the pipes. Wherever the current leaves a pipe it carries some of the metal with it, and if there is much current a hole will soon be eaten into the pipe. As the pipes are mostly covered with rust, which is a partial insulator, the current will be most likely to enter and leave the pipe at some point which is comparatively bright and the electrolytic action will be concentrated at such points.

Heating by Electricity. The electric heater is simply a coil of wire through which enough current is caused to flow to produce quite an appreciable amount of heat. In the use of resistance coils for nearly all electrical purposes the function of the resistance coil is to cut down the flow of current required at some point, as for instance, where a resistance coil is used as a starting box on a motor. The flow of current across or through such a coil or coils, will produce heat, and shows one way in which electric power can be converted into heat. Another instance, if a contact is poorly made, the resistance to the flow of current offered by this contact produces heat and a consequent loss of watts. The voltaic arc in an arc lamp is another instance where resistance to the flow of current is interposed in the circuit and consequently produces heat.

The incandescent lamp is another instance where resistance is the cause of the production of heat, but, of course, in both the arc and incandescent light, the result desired is a maximum amount of light with a minimum amount of heat.

If we were to construct a coil of small wire, whose total resistance would be the same as that of another coil of large wire, it would be found that the coil of small wire would contain much less wire than the coil of large wire, both resistances being the same in ohms. Now if both these coils were connected across a circuit, we will say of 110 volts, the same amount of current would flow over both the coils, because their resistances are alike, but the smaller coil would get quite hot, while the larger coil would perhaps be just slightly warmed. The number or quantity of heat units gi en out by both coils are the same. The surface from which these heat units pass out into the atmosphere is much less in the smaller coil than in the large one, hence the smaller coil gets quite hot, sometimes even red hot. If we were to permit current to flow over this small coil and maintain its temperature at a low red heat, it would in time become oxidized by the chemical action of the oxygen in the air. To prevent this oxidization we may imbed this small coil in a porcelain cement, and after it has been properly imbedded in this cement we will put the entire coil and cement through a baking process, making the cement quite hard and sealing the wire coil from the influence of the oxygen in the atmosphere. Then we can take this coil so constructed and produce heat in a flat iron, or in a stove, in a curling iron, soldering iron, and in fact anywhere. The coil being so hermetically sealed it can also be used in chafing dishes, tea kettles, water urns, glue pots, etc. The principle of producing heat by electricity remains the same no matter where or how it is applied, the only difference necessary being in the form given to the heater coils.

Heating by electricity is quite an expensive and uneconomical proposition, and an idea can be obtained as to the quantity of current necessary to do electric heating, when we consider that in very cold weather it requires nearly as much power to operate the heaters in a street car system as it does to propel the cars.

CHAPTER XV

Lightning Arresters. Lightning arresters are needed on overhead, outdoor lines only. The simplest form of lightning arrester consists of two bare metal plates set very close together, but under no circumstances allowed to touch each other. (See Fig. 109.) One of these plates is connected to the overhead line and the other to the ground.

A sudden flow of current meets with an enormous opposition when it encounters the coils of a large electro magnet. Although the resistance of the air space between the two plates forming the lightning arrester may be several millions of ohms, it is far easier for the current to jump this air space in such a very short time as is taken up by a lightning discharge than it would be to force its way around the coils of the magnet. The reason for this is, that a current of electricity flowing through the coils of an electro magnet creates magnetism or lines of force. These lines of force cut through the coils on the magnet and in that way tend to produce a counter current, or counter electromotive force, which, for a very short time, is almost equal to the electromotive force creating it. Were the current flow to continue for any appreciable time this counter electromotive force would disappear entirely as soon as the magnetism reached its final strength.

In order, therefore, to facilitate as much as possible a lightning discharge towards the ground and away from the machinery and buildings, the wires leading from

the arresters to the earth should be run in as straight a line as possible and be kept well separated from metal parts, especially iron, of the building. Under no cir-

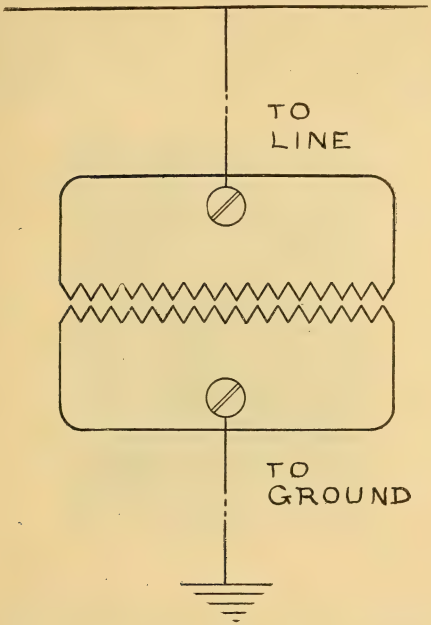


FIGURE 109.

cumstances should the ground wire be run in an iron pipe, nor should lead covered wires be used.

With the simple lightning arrester shown above there is great liability of the current from the dynamo following the arc caused by the lightning discharge to

ground, and, as there must be two arresters, one on each side of the dynamo, this amounts almost to a short circuit and is very likely to put the dynamo out of service. Should such an arc continue for a few minutes, it may fuse the plates of the arrester. The arc can readily be extinguished by blowing it out or causing a strong blast of air to strike it.

To prevent trouble of this kind the Thomson light-

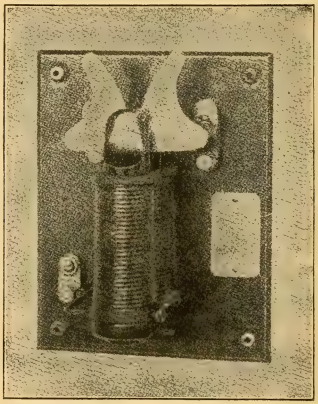


FIGURE 110.

ning arrester, shown in Fig. 110, was devised. This consists of the two diverging metal plates shown at the top of the figure, one of which is connected to the earth and the other to the line to be protected and an electro magnet, as shown. The current from the dynamo traverses the coils of the electro magnets. The action is as follows: When a lightning discharge through the arrester takes place, it forms an arc

between the lower points of the plates above the magnets. These plates are very close together at the bottom. Now the electric arc is always strongly repulsed by a magnet, and hence the arc formed is forced upward where the plates diverge, and the space becomes too great for it to be maintained and it is then broken. The arc is virtually blown out by the magnetism.

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